Benefits of Lean Construction for Affordable Housing

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Topic:

BENEFITS OF LEAN CONSTRUCTION FOR AFFORDABLE HOUSING

Background

International human rights law recognizes everyone's right to an adequate standard of living, including adequate housing. Despite the central place of this right within the global legal system, well over a billion people are not adequately housed. Millions around the world live in life- or health-threatening conditions. The lack of housing cause other social impacts as violence, poverty and health impacts.
The application of Lean Construction methodology for affordable housing can create more attractive scenery and increase profit and quality in the construction of social housing. The Lean Construction is the application of Lean Production in the construction industry management. The Lean Production system was developed in Japanese car industry, and implemented concepts and procedures to a more efficient production, almost waste-free.

Goals for the study

This research analyses the usage of Lean Construction Management for construction of affordable housing. Existing study cases will be analysed to enable the identification of the main challenges faced during the implementation. This research aim is to write recommendations how to avoid and minimize these main challenges.

Research questions

1) What is lean construction and can it be used as a solution to produce low-cost housing?
2) Is it possible to list the benefits of the Lean Construction management to affordable housing construction, which are they?
3) How could Lean Construction support affordable Housing?
4) Are there difficulties to implement the Lean Construction techniques to the construction of affordable housing, which are they?
5) Is possible to minimize or avoid this implementation challenges? How?
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Abstract

This paper presents an analysis of existing case studies of the application of the lean construction principles in affordable housing works in different countries of the world, including case studies in South America and Africa. Bring up the topic of lean construction, technique derived from lean thinking, philosophy enshrined in the manufacturing supply chain. When applied to the construction industry and covering different areas, not only production, but also product development, supplier relationships, strategy management and people management, it is used to meeting a new customer profile, which increasingly demands products with quality, better performance and lower cost. The application of the method demands a significant level of involvement by the company with the lean philosophy, representing an important step towards improving the management, search for better results, quality assurance processes, reducing losses and, therefore, improving productivity.

Key words: Lean Construction; Affordable Housing; Lean Management.

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List of Abbreviations

AEC - Architecture, Engineering and Construction

ERP - Enterprise Resource Planning

FBI - Federal Bureau of Investigations

HR - Human Resources

IT - Information Technology

LC - Lean Construction

LP - Lean Production

LPS - Last Planner System

LT - Lean Thinking

NGO - Non-governmental Organizations

PPC - Percentage of Plan Completed

RPS - Reverse Phase Schedule

SWLA - Six Weeks Look Ahead

TPS - Toyota Production System

UN-HABITAT - United Nations Habitat Division

USA - United States of America

WWP - Weekly Work Program

1) Introduction

The construction industry plays an important role in any economy. Since this industry mobilizes a great chain of resources before, during and after its activities, it represents an important part of the Countries Gross National Product.

In other hand, the profit margins decrease every year in this industry due to the competition, the resources prices and other economic issues, as fees and taxes. Which means that the Construction Industry needs to improve managerial tools and reach adequate levels of efficiency and productivity to remain profitable, as emphasized by Koskela (1992).

A lack of housing for the low-income population is a problem in many countries, especially in the developing economies. But it also occurs in developed countries, that nowadays struggles with support housing for their population and for refugees, as have been happening in Europe for the last five years.

Besides the increasing demand for affordable housing, this target group play a small role in the construction industry. In accordance with the publication of National Low-Income Housing Coalition (2017), the private market does not invest frequently in affordable housing due to the risks of not cover the development and operating costs for the new constructions. This market behavior pushes the responsibility to invest in affordable housing to governments and non-governmental organizations that are involved with affordable housing.

The private market maintains the orientation to build for middle and high-income population, and this occurs because the expectation of a faster investment payback period and avoid or minimize the risk to have any negative impact in the profitability.

This aspect can be analyzed as an opportunity to generate employment and to develop the economic situation by propelling the construction industry to build affordable housing for social interest.

It can be also an opportunity to increase the business area of the AEC industry. If considered as a potential market share, where are future clients with a real demand, it is possible to achieve profit due to the scale.

A shift on the focus is necessary, once that the results will depend on the number of units produced, and the payback period can be larger if compared to the production of houses to middle and high-income families. Nevertheless, there is a potential market that needs to be better studied and considered.

The application of better management approaches and the opportunities to develop this market in special economic situations, as crisis in the construction industry, can be an attractive for private investors.

Once that the same profit and productivity challenges in the construction industry are a reality for the construction of affordable housing, the improvement of management techniques can lead to a more efficient and effective construction activity.

Affordable house can be understood as providing accommodation that is affordable to people on low incomes, very low income and without income, as explained in different research papers, from authors like J. Woetzel, S. Ram, J. Mischke, N. Garemo and S. Sankhe (2014). That is part of governmental policies around the world.

The application of the Lean Construction to the construction of affordable housing can generate benefits as: less waste, reduction in time construction, improvement in the quality of social housing construction and profitability to the constructors.

1.1) Background

International human rights law recognizes everyone's right to an adequate standard of living, including adequate housing. In accordance with the United Nations Habitat, Fact Sheet number 21, "despite the central place of this right within the global legal system, well over a billion people are not adequately housed. Millions around the world live in life- or health-threatening conditions, in overcrowded slums and informal settlements, or in other conditions which do not uphold their human rights and their dignity. Further millions are forcibly evicted, or threatened with forced eviction, from their homes every year."

This important report also highlights the possible future impact of the lack of actions concerning housing, "By 2030, about 3 billion people, or about 40 per cent of the world's population, will need proper housing and access to basic infrastructure and services such as water and sanitation systems. This translates into the need to complete 96,150 housing units per day with serviced and documented land from now until 2030. Unfortunately, especially in the developing world, supply is often limited by inadequate governance systems and human resource deficiencies, as well as by institutions and regulations which are either obsolete or lacking in capacity, or are poorly informed."

On the other hand, the construction industry goes through profit margins decrease every year, due to the competition, the resources prices and other economic issues, as fees and taxes. Which means that the Construction Industry needs to improve managerial tools and reach adequate levels of efficiency and productivity to remain profitable.

Other major problem in all the construction industry is the waste of raw materials, time and resources. According to Formoso (1999), the waste in the civil construction industry includes both, waste materials and waste by performing unnecessary tasks, that generate additional costs and do not add value. Such losses are the result of a low-quality process, which not only increase costs, but also a final product of poor

quality. The same author points out that large portions of these losses become predictable and preventable by adopting simple measures prevention, such as the introduction of new methods and management philosophies.

The construction of social housing is in general linked with lack of quality and non-profitable work for the constructors, owing to the limited budget to develop this type of constructions.

This is an opportunity to apply the Lean Construction concepts in the construction of social housing. Once the concepts are centered in turn the construction processes waste free, increase the work quality and the profit of the constructor, the alignment of the methodology can bring benefits for both sides of the chain, the constructor, who needs to have profit and generate economic development, and the population in need of housing, with the delivery of better quality products.

1.2) Objectives

This research aims to analyses the usage of Lean Construction Management for construction of affordable housing. Existing study cases will be analyzed to enable the identification of the challenges faced during the implementation and the benefits brought to the projects.

Research questions:

1) What is lean construction and can it be used as a solution to produce low-cost housing?

2) Is it possible to list the benefits of the Lean Construction management to affordable housing construction? Which are they?

3) How could Lean Construction support affordable Housing?

4) Are there difficulties to implement the Lean Construction techniques to the construction of affordable housing? Which are they?

5) Is possible to minimize or avoid this implementation challenges? How?

1.3) Research Scope and Boundaries

This research limits to analyze case studies of the application of the Lean Construction concepts during the construction of affordable housing. It analyses the possible benefits and the faced challenges during the implementation of the Lean Construction management for the affordable housing construction. As a result, recommendations on how to avoid and minimize these main challenges will be written. The case studies are an important part of the study, and the ones analyzed in this thesis are one in Brazil, one in Nigeria and one in Ecuador.

1.4) Research Method

In order to achieve the research objectives, a bibliographic revision was conducted. The research of articles and books about Lean Construction methodology and concepts enabled an understanding of the topic and how the application in the construction industry has been developing.

The same methodology was used to lead a comprehension about social and affordable housing, the social impacts caused by the lack of housing in different countries and the problems caused by the mentioned lack.

The study of existing study cases in which the Lean Construction methodology was applied in the construction of affordable housing will be conducted to analyze the positive impacts of the use of the methodology and the different challenges faced to implement Lean Construction in the construction of social housing.

The study cases were chosen in accordance with available data and in different countries, in order to foment the collection of best practices in the application of Lean Construction for social housing construction considering general terms.

1.5) Research Structure

The work is structured into six chapters.

After this presentation, chapter 2 refers to the concepts of social housing and affordable housing, and the social impacts caused for the lack of appropriate housing.

Chapter 3 refers to the concepts of Lean Production and Lean Construction.

The following chapter, number 4, is devoted to the description and analysis of existing case studies, mainly conducted on literature revision. The recommendations to avoid or minimize the main challenges faced in the case studies analyzed are also included in this chapter.

The research questions are answered in chapter 5, as a way to summarize the results found during the execution of this master thesis.

In the sixth chapter is presented this paper conclusions and listed recommendation for future researches.

Once that the lack of appropriate residences and appropriate management of resources in civil construction are matters of global interest and impact, recommendations for future studies in these fields are suggested.

2) Affordable Housing and Social Housing

The definitions and the concepts of affordable housing and social housing vary across literature and country. It is not uncommon that these concepts can be related to each other, that they overlap or are even used with the same meaning. This chapter aim to narrow the definitions and concepts as they were understood and applied in this master thesis.

It will be defined that affordable housing is related to a financial component, the share of income devoted to housing, as described by J. Woetzel, S. Ram, J. Mischke, N. Garemo and S. Sankhe (2014). Still in this matter, the literature points that housing affordability is related to compromise at not more than 30% to 40% of the family earnings with housing, and authors, non-governmental and governmental agencies report, relate the affordability with these numbers, for example, SGS Economics and Planning (2013), NWS (2012), J. Woetzel, S. Ram, J. Mischke, N. Garemo and S. Sankhe (2014), Shelter UK (2010) and City of Melbourne (2009).

The concept of Social Housing encompasses, more often, the development of programs to assist the part of the population that is unable to afford suitable housing in accordance with the supply available in the private market. In general, Social Housing is a matter of governmental policies, and it is directly linked with social safety, health and security conditions. For this reason, the definitions and the scope of Social Housing programs vary from one country to the other, and, sometimes, can even vary inside different states or regions in the same country. Canada Government, for example, includes in their social housing policies special devoted programs for seniors, handicapped persons, native people, victims of family violence, single-parent families and the working poor (Government of Canada, 1993, Section 26,1).

It is globally known the difficulty of governments in solving the lack of appropriate housing, and, more often, not-for-profit organizations are working in this field. This type of partnership, normally, provides housing for a more specific target group, for example, handicapped persons. In order to differentiate government-led residential programs from those carried out by non-governmental organizations, NGO’s, the last one is commonly referred to as Community Housing, SGS Economics and Planning

(2013).

As mentioned before, the concepts and definitions are correlated and usually overlap each other. An understandable example is: a government program to provide housing for low income and very low-income population can be defined as Social Housing, but these families will pay not more than 30% of their income, for the right to live in these houses, fitting to the definition of affordable housing. It is possible to understand that concepts are not necessarily exclusive, but often complementary.

The figure below aims to encompasses the concepts and picture how they are related:

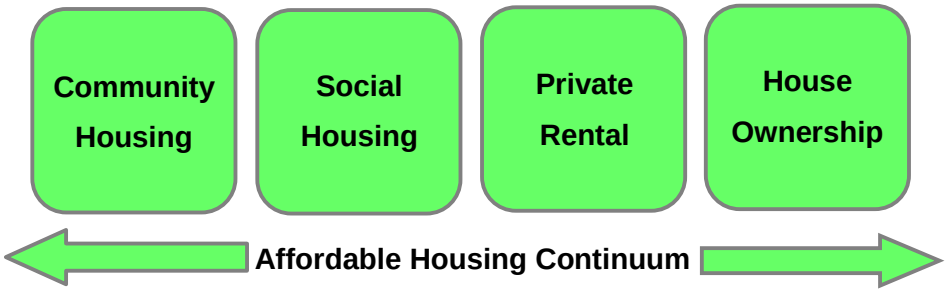


Figure 1: Affordable Housing Concepts

(SGS Economics and Planning 2013, adapted from Fig. 23, pg. 49).

From the figure above is possible to understand that the concept of affordable housing encompasses:

- the available houses with private owner that are available in the market for rent and sell, keeping in abeyance the supply and demand mechanisms;

- the houses provided by public agencies and government, which target is related to low and very low-income population;

- and the houses provided by non-governmental organizations, that also have special target groups, for example: low and very low-income population, people with disabilities, senior citizens and single parents.

The case studies analyzed in chapter 4 are related to affordable housing financed by public agencies and government. In general, affordable housing projects present an

important dependency of governmental policies and funding. Or they are directly funded through governmental actions or depend, in some level, of the governmental incentives to the low and very low-income population housing.

2.1) The Social Impacts of the Lack of Appropriate Housing:

The lack of appropriate and affordable housing is a concern of governments around the world, due to the wide impacts it represents to the society and because of the secondary costs it brings to the public services, as health, security and education.

The problem demands a high level of planning and effort of both, public and private, initiatives. Once that, the lack of planning can lead to impacts in the social relations:

- the lack of planning for the cities can push the low-income population to the furthest areas from the city center, leading to income segregation within urban neighborhoods (Barnes 2012).
- the poorest population tend to be located in areas with less infrastructure, what increases the feeling that they are neglected by the public authorities;
- the impact of gentrification can increase the image of a city that excludes groups from the social life.

Authors as Randolph and Holloway (2005) and Hamnett (2003), describe gentrification as the process of residential movement into inner cities and the subsequent urban redevelopment of economically depressed areas. Atkinson et al. (2011) use a definition more related to the population income, stating that gentrification is the movement of higher income households into lower income neighborhoods.

The impacts above described were highlighted by the authors Wulff and Reynolds (2010). According to both, house prices and rent levels are a determinant key of the social and spatial configuration of urban areas. They defend that a lack of diversity in housing can make a city more polarized. The negative impacts from polarization come from a diminished access to services, programs and other economic functions of the city. It also restricts access by low income households to affordable housing in areas that are better structured.

The UN-Habitat recognizes the impact of the lack of appropriate and affordable housing within the social relations and stated that “Access to adequate housing can be a precondition for the enjoyment of several human rights, including the rights to work, health, social security, vote, privacy or education. The possibility of earning a living can be seriously impaired when a person has been relocated following a forced eviction to a place removed from employment opportunities. Without proof of residency, homeless persons may not be able to vote, enjoy social services or receive health care. Schools may refuse to register slum children because their settlements have no official status. Inadequate housing can have repercussions on the right to health; for instance, if houses and settlements have limited or no safe drinking water and sanitation, their residents may fall seriously ill.”

2.1.1) The impacts on Health and Wellbeing

The negative impacts of the lack of appropriate and affordable housing affect not only the social relationship, but also the health and wellbeing of the population, causing side effects on the costs of the public services related to health.

Mullins and Western (2001) conducted their research using data from a South-East Queensland Quality of Life survey, that establishes connections between poor housing and poor health, economic circumstances and mental health; living in areas of high crime and poverty; low educational attainment rates and success for children and low levels on employment.

It is possible to conclude that the lack of appropriate and affordable housing and poor health and wellbeing occurs simultaneously.

However, the causal links between poor housing and the negative impacts on health and wellbeing are not directly settled.

Anyway, other researches establish a relationship between health and housing. Waters (2001) found that owner occupiers have better health outcomes. This is supported by more recent analyses by Foster (2011). Waters (2001) also pointed that renters report poorer health status and higher rates of serious health conditions, when compared to the reported by property owners.

When related to health, the authors Mullins and Western (2001) noticed an improvement in the general health condition of people who move into better housing. Besides this, improvement presents a small magnitude when compared to the general population, it certainly produces an impact on the costs of public services dedicated to the health of the citizens.

With the outcome of the literature review is possible to affirm that the population' poor health quality, as a reflection of inappropriate housing, produces negative impacts in different public services, causing an overload in the need of medical care, for example, and in this aspect, increasing the management costs of the public health assistance systems.

The health problems in large communities where the lack of appropriate and

affordable housing is present, cause direct impact in the wellbeing and can also be related to mental illness. These communities often report the feeling of being abandoned by the authorities and excluded from public policies.

This can be one of the causes of this interesting found of Mullins and Western (2001), that have also been confirmed by Stone and Hulse (2007): areas of low-income, and subsequently lack of appropriate and affordable housing, develop high levels of community connection. Once that the areas where the low-income population tend to occupy and live are, in general, far from the city centers and have poor infrastructure, this population creates stronger groups and communities, which aim to support each other and pursue representatives among the public authorities.

Other important aspect is how experiencing poor housing during the childhood can, not only, affect the child health and development, but also cause negative impacts during the adulthood.

During the childhood, the human body develops the defense cells and the immunological system, Dockery et al (2010) pointed that poor housing has levels of impact related to the children's age. Young children suffer more with respiratory illnesses when they are inserted in poor physical conditions, for example. Also, children are vulnerable to the neighborhood dynamics, as lack of infrastructure, poor health assistance, access to proper water sources and good sewage networks. Dockery (2010) emphasizes the fact that the child development effects were carried into adulthood.

In a cause and effect chain, children living in poor housing suffer with health problems that affect their development and will produce negative impacts even during adulthood. For Marsh et al. (2000), housing deprivation leads to a greater risk of disability or severe ill-health.

The lack of proper housing encompasses the lack of affordable house, the lack of appropriate spaces, as open areas and overcrowded spaces, restricted access to bathrooms, kitchen facilities and hot water.

It is possible to assume that a direct relationship between the lack of proper and affordable housing, and health quality and the population wellbeing exists, once that different researches lead in this direction. From these facts, the conclusion that

assures proper housing during the childhood brings mid and long-term benefits to the society is possible.

2.1.2) The crime and Violence Component

Other important social impact of the lack of housing is related to crime and violence. Despite the causal relationship has not been clearly established and direct measurements are still needed, researches and studies already point that there is a connection between the lack of housing and the increasing in violence, crime and delinquency.

FBI Uniform Crime Report (2005) and Harrison, Paige M., and Allen J. Beck. (2006) analyzed the data available for the United States of America, USA, and were able to affirm that an increase in expenditures with affordable housing has direct impact in lower crime rates and lower prison incarceration rates. Their findings are presented in the table below.

	2000	2005	Percent change (2000-2005)
Housing expenditure as a percent of total expenditure	1.50%	1.70%	10.74%
Corrections expenditure as a percent of total expenditure	2.80%	2.50%	-10.62%
Violent crime rate	506.5	469.2	-7.36%

Table 1: Relationship: Crimes X Affordable housing

(Justice and Policy Institute, 2007, adapted from table, pg. 10).

In this table, the rate of violent crimes is calculated per 100.000 people in the population and refers to crimes as murder, rape, robbery, and aggravated assault.

Researches conducted in USA, with prison population, found that between 24 per cent and 34 per cent of sample had been homeless at some time during the two months before being arrested, and 22 per cent of the primary sample had been homeless in the night before arrest (Michaels et al. 1992).

Dellaire (1992) found, during research in Montreal and Quebec, that homeless

persons were about 5.5 percent of the normal capacity of detention facilities.

Hewitt (1994) and Ficher (1992) approach different reasons why homeless are involved in criminal activity, however, both authors point that for homeless people the criminal activities may be the only survival way. Once that the lack of housing lead to higher difficulties to find employment, continue education and reach stable life.

Notwithstanding the problem of lack of appropriate housing, the gentrification phenomenon is increasing homelessness.

Atkinson (2002) outlines problems that arise from displacement, which contribute to an environment more prone crime. The displacement includes evictions, due to the inability to afford the rising price of rent associated with gentrification. The author also remarks the fact of possible social conflicts caused by feeling in the current inhabitants that the area is being “invaded” by the new residents.

The gentrification has direct impact in the growing number of homeless and also in the aggravation of the social problems that are a result of the lack of appropriate and affordable housing, including the questions regard to crime and violence.

It is necessary to understand that the crimes have an impact on the entire Justice System costs. When the crime rate increase, more police contingent is needed, therefore more cars and fuel, more guns and ammunition. And if, as a result, the prisons numbers increase, also the costs to keep the criminals in jail are added to the sum.

Also, a high level of criminality will affect the entire population, decreasing the life quality and the wellbeing feeling, what can lead to psychological illness as anxiety and panic, causing a secondary effect on the health system costs.

The lack of appropriate and affordable housing impacts the population that are affected by the problem in a direct way, which means that population that lives in overcrowded spaces, have not appropriate access to kitchen facilities and hot water, have no access to proper toilets or do not have a house, are homeless.

But the impacts on the society affect the entire population and have a decisive role when comes to the public services costs.

The lack of housing is directly related to health problems during the childhood and

adulthood, it is also related to increasing on crime rates and the demand of financial resources for public safety.

The lack of appropriate and affordable housing is a global problem faced by developing and developed countries, dedicating financial resources and policies to the issue will bring benefits not only to those who are in need of a house, but also will cause positive side effects to the society and to different aspects of the government's costs.

3) Lean Construction

As mentioned in the introduction of this thesis, the civil construction industry plays an important role in the country economies. Since it is an industry that mobilizes a grant chain of resources before, during and after its activities, it represents an important part of the Countries Gross National Product.

The increasing competition in the AEC industry, the pressure of taxes and operational costs, the improvement of norms and regulations, the growing in the use of technology in the civil construction industry, and clients demands for the projects accomplishment within the cost, time and quality agreed, challenge civil construction companies to improve their management. The production management has a crucial role in the costs management, in identifying and eliminating waste and in the time for project accomplishment monitoring and controlling (Souza, 2004).

In the early 1990's, emerged the concept of adapting the Toyota Production System to be applied for the management of civil construction projects, as an important tool to improve the AEC industry management.

This chapter presents what the Toyota Production System is, how it was adapted to be used for the civil construction projects and which are the Lean Construction principles.

3.1) Toyota Production System and Lean Manufacturing

Nowadays, The Toyota Production System is known all around the World as a manufacturing management method and a tool to reduce waste during the production and increase the final product quality and value.

The TPS is now understood as more than simple tools and management approaches, and it is described as the Toyota Way, a definition that encompasses all the philosophy behind the TPS. This philosophy started to be constructed since the early foundation, in the late 1880s, by Sakichi Toyoda, as a family business (Liker, 2004). Sakichi had a spinning and weaving machines business, and improved the systems by trial-and-error approach, molding the concept of getting the hands dirty as a way to understand and improve the production, which is an important concept of

the TPS, Liker (2004). Mr. Toyoda continued dedicating time and efforts to improve his machines and the production, behavior that culminate in other two concepts of the TPS: the continuous improvement and the Principle of Mistake Proofing, *jidoka* (Fujimoto, 1999; Liker, 2004).

The Toyota Motor Company was founded in 1937 by Kiichiro Toyoda, Sakichi Toyoda son. Kiichiro kept the continuous improvement of the production, introducing the Just-in-Time philosophy for the materials management (Liker, 2004).

During this period, Toyota engineers had their first contact with the Just-in-Time concept, described by Henry Ford (1930), “We have found in buying materials that it is not worthwhile to buy for other than immediate needs.”, they realize that the concept of having the materials only at the moment that they are needed is an opportunity to decrease the space necessary for storage and the maintenance costs of the places and the stock footage. Just-in-time become a very important part of the TPS philosophy, being considered as one of its most important pillars.

Besides the Just-in-Time concepts have emerged in the USA automotive manufacturing industry, and started to develop in many businesses in the country, the TPS incorporated it to their production system and improved it, achieving excellent results with its application, especially regarding to space management, space waste and production layout improvement.

The Just-in-Time was described by Ohno (1997) as the time when the needed parts reach the production flow, and this should occur in the exact time of the usage and in the exact amount of necessary parts. If this balance is optimum, the production will reach a zero inventory, what is the ideal condition. The author emphasizes that the complexity of the processes has direct impact in the adoption of the Just-in-Time, once that as more parts are necessary during the production, more complicated will be to manage the flow of the production.

The Just-in-Time philosophy also involves the participation of the workers in the quality and control process. This occurs because the workers are responsible to identify the errors and correct them, once that the internal clients will be able to identify productions delays, the workers will commit with their own phase, to assure the entire production flow to not be interrupted.

The World War II impacted the car selling and the Toyota Motor Company faced financial problems that resulted in the retirement of Kiichiro Toyoda and the

nomination of Eiji Toyoda as the managing director of manufacturing. According to Holweg (2007), Eiji promoted the travel of Toyota delegations to Germany and USA in 1950, and his intention was to study other manufacturing methods.

The literature often highlights that the productivity of the car companies in USA impressed Eiji, who decided to adapt the mass manufacturing systems used there to be used in Japan, despite the differences between the market conditions of both countries, fact observed by authors as Sugimori (1977), Liker (2004), Holweg (2007) and Osono (2008).

According to Sugimori (1977), the engineers Taiichi Ohno and Shigeo Shingo were responsible for adapting the good practices, observed during the exchange period visiting the industries in the USA, to the Toyota culture and the Japanese market particularities, which is one of the important concepts of TPS, do the Benchmark.

TPS is a production philosophy focused in improve the profit eliminating waste, practicing the continuous improvement of the processes, using the resources in the needed time, Just-in-Time, respecting people and applying automation to facilitate the production.

Taiichi Ohno was also responsible for disclosing the changes made at the production and spread the Toyota Production System as a management efficient tool, which he did with his book Toyota Production System: Beyond Large-scale Production, from 1988.

Some of the differences between the traditional mass production system and TPS are listed in the table below:

	TPS	Traditional Production
Inventory	Is based on the utilization flow of one piece	Is related in consumption projections and large batches
Parts to be produced	Produced when the customer order, pull system	Done with sales forecast , pushing system.
Products Pool	Big diversity of products, produced in small portions of each	Small diversity of products, produced in large quantities
Quality	Assured with control during the whole production	Tested with random samples
Worker participation	Are encouraged to continuous improve the processes	Act as mechanical part of the processes
Problems	Are improvement opportunities	Are just problems to be solved

Table 2: Differences: TPS and Traditional Production

(By the author).

3.2) Lean Manufacturing

In 1990 James P. Womack, Daniel Roos, and Daniel T. Jones launched the book “The Machine that change the World” and used for the first time the concept of “Lean Manufacturing”, to describe the application of TPS concepts as an example to be followed by the USA car producers in order to improve the production.

Since then, the concepts of TPS and Lean Manufacturing are used to describe similar management tools, focused in identify and eliminate waste, production continuous improvement and a wide understanding of processes and people interaction.

In 1996 Womack and Jones, in the book “Lean Thinking”, introduced the Lean Thinking principles: Value, The Value Stream, Flow, Pull and Perfection.

- **Value:** it is defined by the customer. Once, it is necessary to be in constant contact with the customers and understand what the perception of value is, being able to create and deliver the product that fits to their needs, providing the maximum value;
- **The value stream:** it is the understanding of all activities that are relevant to create and deliver a product. During the study of the production will be possible to identify waste and unnecessary activities;
- **Flow:** it is the production pace. The study of the value stream will enable to understand the current production flow and how it can be improved. Every step of the production should flow in a pace that will add the maximum value to the products;
- **Pull:** the production is not done based on consume forecast anymore. The production focus in Lean thinking is based on customers place a production orders;
- **Perfection:** it is the search for continuous improvement of the processes and production. The commitment of the workers during all production phases with the Lean Thinking principles.

During the value stream study, the types of waste introduced by Taiichi Ohno (1988) can be used to understand, identify and eliminate waste.

Ohno wrote that to eliminate the waste, and optimize the profit, is necessary to

understand what is waste, how it occurs and in which phases of the production. Given this, he categorized the waste in TPS in seven types:

- **Overproduction:** when more than is needed is produced, there is waste of materials, working hours and storage space;
- **Waiting:** if during the production one phase needs to wait another phase to finish so then it can start, time is wasted. The production flow must be continuous and smooth;
- **Transportation:** the products movement during the production processes should be as less and possible, avoiding time waste and product deterioration;
- **Inappropriate processing:** usage of the correct equipment and production process;
- **Excessive inventory:** if there are more parts or products than the necessary, storage places and avoidable maintenance will be needed;
- **Unnecessary motion:** when the workplace obligates the workers to leave their tasks to reach materials or to get what is necessary to accomplish their work, waste of time and resources is happening.
- **Defects:** inspecting flaws only at the end of the production will identify the problems too late, generating inventory and demanding time and money to implement the corrections.

The TPS and Lean thinking concepts have been utilized in large scale since the early 1980's all around the World for manufacturing industries with positive results, improving the production systems, diminishing waste, focusing in the add value production, making the productions more efficient and optimizing the profit.

Once that waste and low profit are also problematic characteristics in the civil construction industry, Ari Koskela (1992) published the article “Application of the New Production Philosophy to Construction”, adapting the TPS and lean manufacturing philosophy to be applied in the civil construction and introducing a new management thinking into the industry.

3.3) Lean Construction Principles and Concepts

The base for the development of lean construction philosophy was the Toyota Production System and the Lean Production philosophies, once that this management approaches were already applied in different manufacturing industries with positive results emerging.

Going through the available literature about the new philosophy and analyzing with criticism the status of the construction industry management, Koskela observed the possibility to use the managerial philosophy in development to improve the quality and results of the AEC industry.

In his work in the Center for Integrated Facility Engineering (CIFE) at Stanford University, in 1992, the author criticizes the traditional construction management in a structure of three groups: lack of quality considerations, segmented control and sequence of project realization, and affirm that from the manufactures exists already evidence that this managerial system is counterproductive.

Koskela defined the eleven principles of the lean construction and described them as being principles for flow process design and improvement. The author highlights that the principles are all related to each other and centered them all in one principle, the Value add.

The eleven principles are:

1) **Reduce the share of non-value adding activities –** the non-value adding activities are those that consume time, resources and space, but do not add value to the project. Reducing as much as possible these activities brings positive impact in the productive flow and in the costs. As examples of non-value adding activities in the construction sites are the unnecessary transport of raw materials to different work stations, the waiting time between the solicitation of materials and the delivery.
2) **Increase output value through systematic consideration of customer requirements** - there are two types of customers, the final one, and the internal one, that can be a next process before the delivery of the final product. The value is a customer perception, in this matter understand and fulfill the customer requirements is to assure that the maximum possible value

will be add to the project.

3) **Reduce variability –** the processes vary, especially in the civil construction industry. The raw materials come from different locations and the construction techniques have specific characteristics. But standardization of processes can minimize the negative aspects of the variability and assure the processes flow.

4) **Reduce the cycle time** – the cycle time is easy to measure and understand. The total cycle is the amount of time needed for one process to start and finish.

   Koskela, 1992, represents it as:

   Cycle time = Processing time + inspection time + wait time + move time

   By compressing the cycle time, as close as possible, to the processing time, assuring the process quality, causes beneficial impacts to cost, time and quality.

   The figure 2 depicts the progression of cycle time reduction:

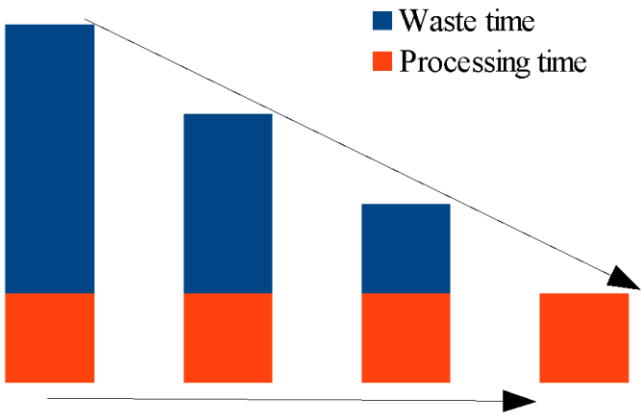


Figure 2: Cycle time compression

(Koskela, 1992, re-draw from Fig. 4 pg. 20).

5) **Simplify by minimizing the number of steps and parts –** the complexity of a process or a product has direct impact in its costs. As more complex a process or a product is, more difficult it will be to understand its parts and flow, which impact in the reliability. In these terms, simplify means eliminate non-value adding activities from the processes and a reconfiguration of the parts

and steps that are value-adding.

6) **Increase output flexibility –** this concept can be a challenge when simply analyzed. Koskela quotes Stalk and Hout (1989) about the success of companies in realize the implementation of both concepts. The author also listed modularized products, the customization to be done as late as possible during the process and trained workforce as approaches to increase the flexibility.
7) **Increase process transparency –** this concept can be implemented with the process organizations, in order to make it comprehensive and visible to every employee. The establishment of how the control will take place and how the measurements will be done is important. A major component is to define the communication about the results, how and when they will be displayed. The communication is the key factor to achieve the workers commitment.
8) **Focus control on the complete process –** controlling the entire process avoids confusion when the flow crosses different units in a hierarchical organization and the risk of do not have a responsible person when the process crosses organizational borders. A process authority can be designated, but the cooperation with suppliers and team building are also beneficial for an optimized flow.
9) **Build continuous improvement into the process –** continuous improvement is an important concept into the lean thinking philosophy. It means to maintain a critical look to the processes and continuously search for ways to improve the activities. Measuring and monitoring the improvement, involve workers at the improvement process, standardization of processes, are methods to implement and stimulate the continuous improvement.
10) **Balance flow improvement with conversion improvement –** conversion here is related with new investments, new equipment and a deeper change in the process. Before the decision to go through the conversion improvement, it is recommended to analyze and improve the existing flow. The implementation of conversion technology will also bring more benefits if the flow is controlled and optimized. Other advantage is that an optimized flow will require less investment in conversion.
11) **Benchmark –** this concept is directly connected with the continuous

> improvement. Benchmark means know your own processes and search at the market for the ones who are known as the best ones for it. Look at them as examples, study and understand how they reached the leadership and apply their knowledge into your processes.

An important and valuable step in the implementation of the concepts of lean construction is the definition of measurements. For every concept that will be implemented should exist a measurement of the actual status and future measurements, to enable the improvement identification or to detect where the implementation is facing more challenges.

Defining what will be measured, with each frequency and which results are expected, could be a time-consuming process, once that the measurement approaches need to be clear and well understood by all the team involved on the task.

The measurements should encompass more than the cost and quality aspects, these are the first aspects to be highlighted, and they are, in general, easy to implement and to understand. But other production aspects related to the principles have to be monitored and measured, because the evaluation of the progress will lead to identify the success and the problems, configuring a necessary tool for the continuous improvement philosophy.

After 25 years of the publication of this important paper from Koskela, the concepts of Lean Construction developed, but efficiency continues to be an issue for the construction companies. The particularities of the construction projects, as the concept that a project is unique, are still barriers to standardize processes and measure them.

One of the main challenges is to identify and visualize the construction as a process which has a flow of activities, and, as consequence, identify the non-adding value activities, as waiting time, become also a question. Due to it is only possible to eliminate waste when is possible to identify it and improve the process, it is a matter of understand in which part of the production flow the flaws are happening.

With these problems being pointed in many situations of the construction industry, the Last Planner technique emerged as a tool to improve the workflow.

Ballad (2000) describe Last Planner System, LPS, as a technique to address the project variables and enable the building and understanding of the workflow. It

evolved from the need to amend the managerial task related to plan and control the productive process.

LPS produces a more efficient schedule for the construction activities because it aims to synchronize the activities considering the resources availability, the work force capacity and improve the communication during the scheduling process.

The success of LPS implementation depends on the commitment of all the parts of the scheduling process, the planners, the executors and the controllers. After the planners analyze what is necessary to be done and with which resources and budget, the executors must be committed to the plan, point out variance and cooperate with the planning team to build a realistic plan.

According to Salem et al (2005) LPS starts with team planning and resources optimization, resembling to the production levelling tools used in lean manufacturing.

The initial phase will be the preparation of the Master Schedule, that is an overall schedule for the project. The level of the details is related to special dates or deliveries during the project, from now on referred as milestones. A more detailed schedule will be produced with the contribution of the team that will be responsible for the work. They will work based on the milestones, and develop backwards how to handle uncertainty and resources. This methodology is denominated Reverse Phase Schedule.

However, to execute the activities, the use of a Weekly Work Plan, WWP, can facilitate the resources forecast and the variance analysis. As part of the continuous improvement, the analysis of the successes and failures during the execution of the WWP should stretch way the problems occurred and what are the actions needed to avoid the future repeating of flaws.

A valuable tool to monitor and control the WWP progress is the percentage of planned activities that were completed, PPC, with success. Ballad, 2000, describes it as percentage plan completed value, what is the number of activity completed as planned divided by the total number of planned activities.

The monitoring of the WWP enable to identify the deviations and analyze their impact on the entire plan. Thereby allowing a fast decision making, taking necessary actions to avoid possible resources and time constraints in the future.

Koskela (2000) underlines the importance of using the schedule and looking ahead in the plan, and wrote “Look ahead planning is the process under take to achieve

possible constraints, free assignment and cut down uncertainty”.

The concepts, tools and techniques related to Lean Construction emerged to face efficiency problems in the construction industry. Since the early beginning, in the 1990s, more approaches in how to implement Lean Construction surfaced from the need to adapt the concepts in different countries and challenging economic constraints.

However, the core meaning remains eliminate waste, optimize resources, increase efficiency leading to profitability.

With the current challenges for the AEC industry, as high levels of competition, low profit margins, increasing in resources prices, especially human resources and the market demand for projects constructed in shorter time, with the expected quality and within the budget, the implementation of LC concepts, techniques and tools has become a managerial need.

When comes to the construction of affordable housing, these challenges have even greater impact. Once this type of project normally faces enormous budget and resources constraints, they are known for lower profitability, and this impact on the project quality during the entire project development.

The implementation of LC concepts, techniques and tools during the projects for the construction of affordable housing has the potential to transform these projects and make them more attractive for the AEC industry.

With this implementation is possible to understand the construction flow, monitoring where, during the processes, the waste is occurring and take the necessary actions to avoid that the profit become extinguished by the waste. It also enables the correct allocation of resources to execute the tasks, helping to prevent the over allocation or the delays due to the lack of resources.

The success for the construction of affordable housing for the AEC industry perspective is strongly related with the implementation of Lean Construction.

3.4) Barriers to the Lean Construction Implementation

In order to overcome the market challenges, the AEC industry must improve its managerial tools and philosophies. However, adopting new managerial approaches requires a cultural shift and commitment that is not always available

Adopting a new managerial approach implementing the LC concepts is a challenging process, and research is commonly conducted to identify the main causes of failure during the implementation process.

These researches are important because they provide a tool to the companies implementing LC to understand the main and more common barriers that appear during the process, and also a benchmark about how other companies had removed the constraints during the implementation. According to Leong and Tilley (2008), an organization that does not understand the factors that affect the implementation of LC is not able to lead and focus the necessary efforts to obtain better results.

The first barrier to be overcome is the belief that it is not possible to apply management philosophies and approaches from the manufacture industry to the construction industry. Salem (2006), describes the construction project as one-off project based, more complex and liable to have uncertainties and constraints. The fact that the construction process results in a unique product is also a reason used to argue that the manufacturing approaches do not fit to the construction industry, what is not necessarily truth, once few processes and tasks are repeated.

Other characteristic of the construction industry that is often challenge in the implementation of Lean Construction principles is subcontracting during the projects. To Mossman (2009), subcontracting in construction increases the challenges to the participants cooperation and the creation of an environment favorable to joint learning.

Obviously, the increased number of subcontractors has direct impact in the number of communication channels needed during the implementation of Lean Construction principles. Abdullah (2009) emphasizes that a bad communication management will

impact negatively on the project effectiveness and on the implementation coordination.

Procurement and contracting with subcontractor are important to avoid the traditional models that place the main contractor and subcontractors as opponents. According to Mossman (2009), this type of contract hampers the creation of partnership and collaboration between the contractor and subcontractor, necessary to the LC implementation.

Once that the implementation of LC demands great amount of human effort and dedication, the human factor is crucial to the success of the process. Many authors conducted researches related to the cultural and other human behaviors that are barriers to the LC implementation, as Johansen and Porter (2003), Salem (2006) and Mossman (2009). Some of the noticed problematic behaviors listed were: scarcity of commitment, lack of ability to work in group, weak communication and transparency, nonexistence of incentives and motivation, lack of trust, and fear of failure.

The pressure due to commercial agreements tends to generate a trend in maintain the traditional management, being the affirmation of shortage of time to implement a new managerial approach very common. Abdullah (2009) alerts that being held to the current management concepts will make the construction companies reluctant to implement changes, even if the changes have potential to improve performance and increase quality and productivity.

The financial issue during the LC implementation should not be ignored. The implementation process demands funding to conduct the team training programs, provide the team with the necessary tools and equipment, create the needed incentives and, sometimes, cover the costs of professional consulting about LC. The insufficient funding to the implementation process results in failure. Mossman (2009) addresses other important aspects, as inflation, unstable markets for construction, lack of incentives and motivation, low professional remuneration, resistance of some companies to invest extra funds to provide training for their workers.

As previously mentioned, the human behavior is often a barrier to the LC implementation. The top management is conducted by humans, and how they handle and behave about the implementation process have direct impact on the failure or success of the LC principles adoption. Abdullah (2009) points out that when the top

management leadership and commitment with the LC implementation are weak, an important barrier to the implementation is created.

As mentioned previously, the subcontracts can affect the LC implementation due to the necessity to involve the subcontractors into the process and their acceptance, regarding the changes that will be needed. Concerning for this, an interface that has great potential to mine the LC implementation, and must be managed carefully, is the interface between design and construction. Rooke (2007) emphasizes that the construction industry usually separates the products' design and implementation, and this division can lead to waste as incomplete or insufficient design, designs that are not buildable, interruptions in the production workflow due to design changes. The management of the interface between design and implementation, or construction, need to be a point of attention during the LC principles implementation.

When a LC principles implementation starts, the understanding of the concepts must be assured and the awareness about the processes will be demanded during the entire implementation. Abdullah (2009) defends that a full comprehension of the LC concepts before is necessary to conduct the implementation process. The same author linked the difficulties in understand the LC concepts as barriers to the successful implementation.

There are educational issues that represents barriers to the LC concepts implementation. Despite the concepts being in constant development in the last 25 years and the efforts to increase the knowledge about them have also being frequently made, the educational barriers continue to hinder the LC implementation. About this issue, the authors Johansen & Porter (2003), Abdullah (2009) and Mossman (2009), list the following barriers: lack of technical skills, inadequate training, poor understanding and awareness, poor team-work skills.

Other important barrier to the implementation of LC principles is the need to establish measurement parameters and systems. The creation of a measurement system can produce a discomfort among the teams. The persons tend to face the measurements as personal evaluations and resist to the implementation, fearing to fail or to be pointed as responsible for the failure. To be able to understand the impact of the implementation of the LC concepts, measurements parameters and systems are needed. It is important to disseminate how the measurement will be realized, with

which frequency and what is the intention with the monitoring and controlling of the results.

The teams involved need to agree with the measurement system adopted and feel comfortable with their implementation. The measurements need to be disseminated as an opportunity for the continuous improvement during the LC concepts implementation.

There are many challenges and barriers to be faced during the implementation of Lean Construction concepts, and authors as Abdullah (2009) and Mossman (2009) identified that some of the barriers appears commonly during the implementations phases. Research regard the challenges is being frequently conducted and in different countries.

Those researchers intent to increase the awareness about the difficulties faced during the implementation processes. The aim is to encourage the persons interested in LC to continue with the implementation when the barriers appear.

Disseminating the most common challenges faced enable the future implementers with the benchmark data on how the other companies and projects overcame the obstacles and how they solved the problems during the implementation of the LC concepts.

Other challenges, due to the project particularity, can happen during the implementation. This chapter highlights only the ones that are more often communicated by those who implemented the LC concepts. The challenges will may vary from one country to another and even from one company to another.

It is important to be aware of the challenges and be prepared to face them, taking the necessary action to overcome them and assure the implementation of the LC concepts success.

4) Case Studies

This chapter is dedicated to analyze existing study cases related to the application of Lean Construction in affordable housing. The cases were chosen based on data availability, and with the aim to picture situations in different countries and continents. The order with which the cases are presented have no influence in the importance or different impact in this master thesis.

The inclusion of existing case studies aims to build the link between Lean Construction theory and the AEC industry, enabling a significant increase in the understanding of how the concepts are applied, which impact can be expected in the projects and the most commonly challenges faced during the implementation.

4.1) Brazil

This study case was conducted by Villa, Silva, Silva, Santos and Diniz in 2014 and published by the Revista de Trabalhos Acadêmicos Universo Recife, Recife Universe Magazine for Academic Papers[1], V.1/N.2/2014.

4.1.1) Case Description

The case study was conducted during the construction of 43 affordable houses, with 40,63m² each, in Pernambuco state, Brazil. The company responsible for the construction is a Brazilian company with expertise in affordable housing projects and it executes related projects in different locations of the North-East of the country.

This construction project was financed by the Brazilian Federal Govern, as part of the federal government policy for the housing program “Minha Casa, Minha Vida”. This program aims to diminish the housing deficit, especially for the low-income and very low-income citizens. The project cost was R$ 1.075.000,00, approximately US$ 400.000,00.

The first step for the implementation of Lean Construction was to identify the waste in the construction sites. To do this, site investigation and review in the record of previous projects were conducted. The information collected in this phase fomented the identification and the quantification of waste related to raw materials and labor.

The following table depicts the waste by category, raw material and labor, and the total waste:

[1] Magazine name translated by the author from the Portuguese.

Location	Number of houses	Raw Material Waste	Labor Waste	Total Waste
City A	40	21.00%	14.00%	17.50%
City B	31	18.00%	20.00%	19.00%
City C	43	22.00%	19.00%	20.50%
City D	44	17.00%	16.00%	16.50%

Table 3: Waste identification and quantification.

(Adapted from figure 3, Villa, Silva, Silva, Santos and Diniz, 2014).

The City C is the project site from this study, and all the implementation data is related to this project.

In order to increase the success probability during the implementation of Lean Construction, the decision was to choose one phase of the project to begin the cultural shift that the new concepts demand. This also enables the better visualization of the implementation process and the results that it brings.

The graph from the costs of all the phases was analyzed to define in which phase of the construction the Lean Construction concepts should be implemented, so it was possible to identify that the activities related to walls and façades consume the higher amount of resources in the studied project.

In Figure 3 is possible to observe the result of the data. Once that the walls and façades activities consume 31,5% of the total resources for the construction project, this process waste has major impact on the entire construction. For this reason, the decision was to proceed the LC implementation through the walls and façades processes.

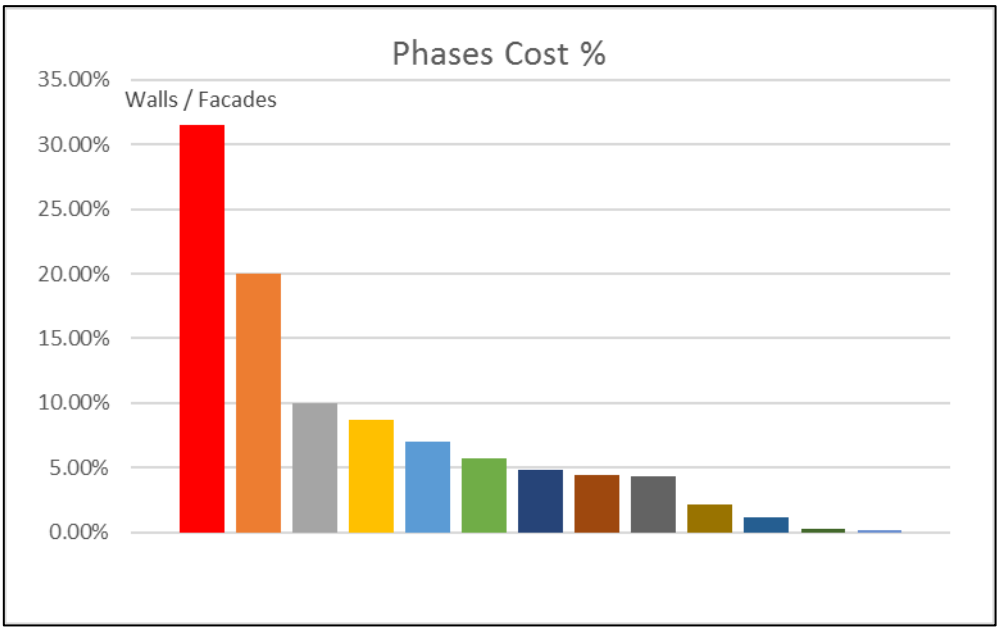


Figure 3: Graph of % Phases costs.

(Adapted from figure 4, Villa, Silva, Silva, Santos and Diniz, 2014).

The following procedure was the identification and quantification of the waste during the activities to execute walls and façades. It was necessary to divide the raw materials waste from the labor waste, where the second one was measured considering the extra time needed for the tasks execution when compared to the planned time.

The Table 4 presents the raw materials necessary for building the walls and façades of one house. The procedure was to compare the planned material usage with the quantities really needed during the execution.

Material	Planned Quantity	Applied Quantity	Waste %
Cement (50Kg)	5.00	7.00	28.57
Lime (m³)	0.80	1.30	38.46
Sand (m³)	1.50	2.60	42.31
Brick (Unit)	2250.00	3100.00	17.74

Table 4: Raw Material waste quantification.

(Adapted from figure 6, Villa, Silva, Silva, Santos and Diniz, 2014).

Once that the labor waste occurs during the whole development of the tasks, after the measurements and to facilitate the comprehension, a single productivity index was adopted and the waste calculated, as depict in Table 5. The quantities are related to the construction of one unit house.

Activity	Time Planned	Time Executed	Waste %
Brick Masonry	5.00	7.30	31.51

Table 5: Labor waste quantification.

(Adapted from figure 8, Villa, Silva, Silva, Santos and Diniz, 2014).

After the waste quantities measurement, the authors considered necessary to calculate the costs of the waste. This calculation leads to more tangible and comprehensive understanding for all the stakeholders involved. The calculated values are displayed in Table 6, and considered for 43 houses.

Material	Unit Cost R$	Applied Quantity	Total Cost R$	Waste %	Waste Cost R$
Cement (50Kg)	23.20	7.00	6983.20	28.57	1995.10
Brick (Unit)	0.45	2900.00	56115.00	17.74	9954.80
Labor (day)	180.00	7.30	56502.00	31.51	17803.78
				Total	**29753.68**

Table 6: Waste Cost.

(Adapted from figure 9, Villa, Silva, Silva, Santos and Diniz, 2014).

The identified wastes were analyzed applying Ishikawa Diagram and the 5 Why's technique, with the intention to understand the reasons why the waste is occurring and, in this manner, be able to produce an action plan, designating responsible people for implementing the actions and measuring the results at the end of the process.

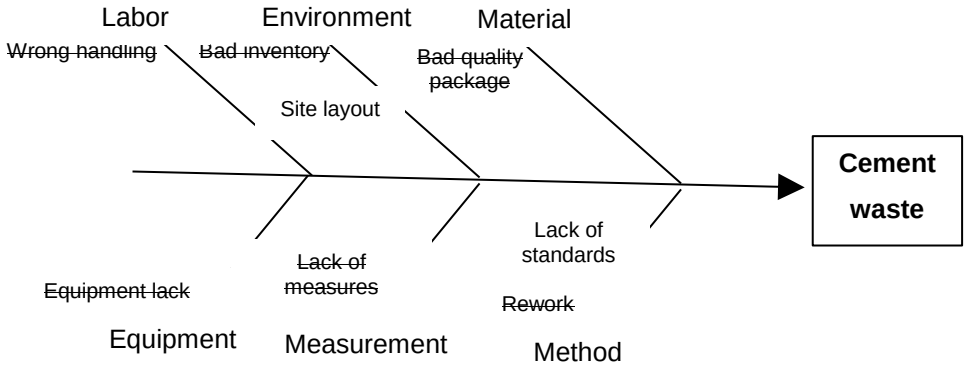


Figure 4: Causes of cement waste.

(Adapted from figure 10, Villa, Silva, Silva, Santos and Diniz, 2014).

The Ishikawa technique was applied to allow the understanding of the causes of the cement waste. During the process, some causes were discussed, as the rework process. After the discussions, the team understood that one of the causes of the cement waste was not the rework, but the lack of standardization to develop the task. Once that there was no standard to develop the work, the variability in the final products was leading to rework and, consequently, waste.

Similar discussion was conducted regarding the non-satisfactory conditions of the inventory. After analysis and discussion, the team understood that the cause of waste was in the construction site layout. Due the inventory placement and the tasks development place distance, the transport of material was leading to waste.

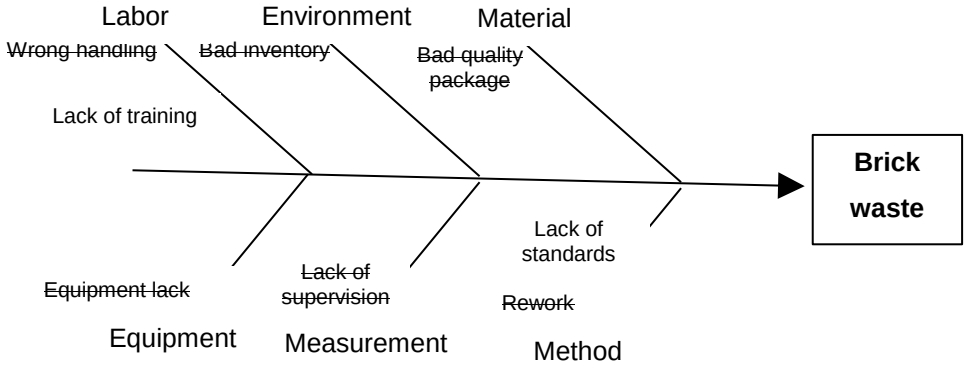


Figure 5: Causes of brick waste.

(Adapted from figure 11, Villa, Silva, Silva, Santos and Diniz, 2014).

The process was also applied to identify the causes of brick waste. In this analysis, the lack of standards was also identified as a cause of the waste. The variability during the construction tasks was affecting the final product and leading to rework and, consequently, to waste of brick.

Other cause identified was the lack of proper training to the works related to the tasks development. Initially, the wrong material handling was pointed as the waste cause, but with discussion was possible to visualize that some of the workers have not been trained in how to handle the materials.

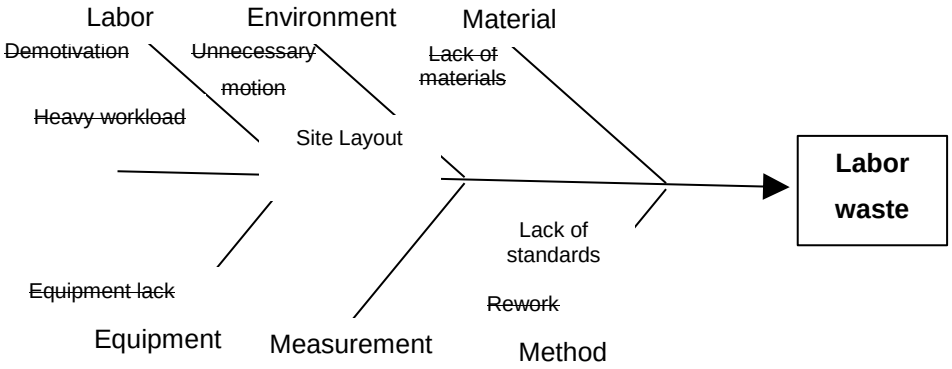


Figure 6: Causes of Labor waste.

(Adapted from figure 12, Villa, Silva, Silva, Santos and Diniz, 2014).

In the analysis to clarify the causes of labor waste, the site layout was contributing to the need of long distance displacements around the construction site.

Again, the lack of standards to realize the tasks was compromising the results, because of the necessary rework that was creating a demotivated environment to the workers.

The process to build the Ishikawa diagrams involved the workers and lead to a more clear and uniform understanding of the waste causes. With this available data was possible to produce action plans and designate responsible people to conduct the implementation of the necessary changes.

From this analysis was possible to identify that the cement waste has two main reasons: the lack of standards during the mortar production and the lack of

supervision of the work. A site supervisor was designated to assure that the mortar specifications in the project need were followed during the production.

The reasons for the brick waste were the lack of laborers training and inefficient layout of the working site. The HR was designated to evaluate the need of trainings and schedule and conduct them; the planning engineers were responsible to evaluate the layout disposition at the construction site.

The working site layout was identified as the main reason for the labor waste. Once that the location of the materials storage and the location of the materials application were far from each other, a considerable amount of time was being needed to move the material from one position to the other. Once again, the planning engineers were designated to analyze and improve the working site layout.

The LC concepts were applied to solve the waste problems described before according to the subsequent approach:

1) **Reduce the share of non-value adding activities –** the construction layout review results in decentralized stocks, eliminating the unnecessary detachments during the tasks development and the non-value adding activities related to the movements.
2) **Increase output value through systematic consideration of customer requirements** – from the internal clients feedback was identified that the lack of standards to execute the tasks was causing delay in the subsequent task and even the need of repeated rework. From this procedure, the work supervision was created.
3) **Reduce variability –** the processes variability is linked with the lack of standard during the processes. The implementation of standards will reduce this variability.
4) **Reduce the cycle time –** the cycle time reduction was improved with the laborers training and the review of the construction site layout. The time to move materials and get tools was decreased.
5) **Simplify by minimizing the number of steps and parts** – unnecessary steps for the task development were decreased after the activity flow analysis. The waste of labor was positively impacted and also the materials waste decreased.

From the eleven concepts of LC, five were applied in this study case. There was significative improvement in the waste reduction after the actions took place.

The authors measured and concluded that the waste cost decreased from R$ 29.753,68 after the LC implementation to R$ 8.523,55 after the action plan be executed.

The cost saving with the diminishing waste was R$ 493,72 per house constructed. The authors suggest that a projection of this savings, if the LC was implemented in all the construction sites from the company, that count with 2000 units of affordable houses, can generate a saving of R$ 987.440,00.

4.1.2) Case analysis

The Brazilian case study presented previously concerns to the partial application of the lean construction concepts in a project for the construction of 43 affordable houses in the North-East area of the country.

The choice of one process as a pilot process is a very good decision. It enables the understanding of the concepts for those involved in the tasks development and also maintain the focus in visualizing and analyzing one of the process, avoiding confusion between the two different flows or their intersection.

Quantifying the raw materials and labor wastes and translating them into costs analysis is a valuable tool to communicate the results, once that all the workers involved in construction activities have a good understanding about the construction costs.

The study case authors concluded that this first implementation and the positive results can be used to motivate a large-scale project of implementation.

From the published paper is possible to conclude that the others Lean Construction concepts can be implemented and will generate benefits.

The projection of the positive results using only the total number of affordable houses being constructed by the company is questionable, once that those houses are located in different cities and the particularities of each project can affect the results. The results can be better or worse than the ones found in the case study, and the intent is to alert that the simple projection is a weak tool, and can be frustrating to the ones involved in the implementation when the results of other work sites do not point in the same direction.

The main challenges to the implantation were the participation and involvement of stakeholders and workers. The main tool applied to assure the commitment of all the members involved was training programs. In those programs, the LC concepts were explained and the contributions from all the participants were taken into consideration during the implementation phase.

The lack of data about posterior monitoring on how the application of LC is still going

on and about the results, if there are still positive results after the implementation, do not permit a long-term analysis.

4.2) Ecuador

This study case was conducted for Martinez in 2016, as part of his Doctor of Philosophy in Engineering - Civil and Environmental Engineering thesis, for the University of California, Berkeley.

4.2.1) Case Description

The case study project is located in Duran, Ecuador, and it is named Villa Hermosa. It was developed with a mixed target, where half of the houses are for low-income families and the other half for middle-income families. The author considers this strategy a way to avoid the segregation by income.

The project consists in the design and construction of a total of 10.000 single and multi-family housing units, and, due to the size, it will occur in different phases in the course of 8 years. The case study focuses on the first phase of the project development, which is the construction of 700 single housing units.

This project does not follow the trend in affordable housing, that is the use of standard houses. It offers the possibility of customizing the houses, and this was a strategic decision from the developer, with the intent on reaching more segments in the market. If, from the sales perspective, the offer of different houses increases the marketability for the design and construction perspective, it can increase the production complexity and the processes variability, what do not meet with the LC concepts. The decision to solve this conflict was to have a limited number of options, in the project case, 12 different designs.

Due to the variability in the products, the implementation of Lean Construction concepts was understood as a path to assure the efficiency during the project processes. Once that the construction focus is cast-in-place concrete, three LC concepts were implemented, as described:

- Selection of formwork system using Choosing by Advantages;
- Formwork system standardization and production flow;

- Planning and controlling concrete operations using Information Technology (IT) tools.

The Figure 7 depicts the link between the project processes and the LC concepts implementation.

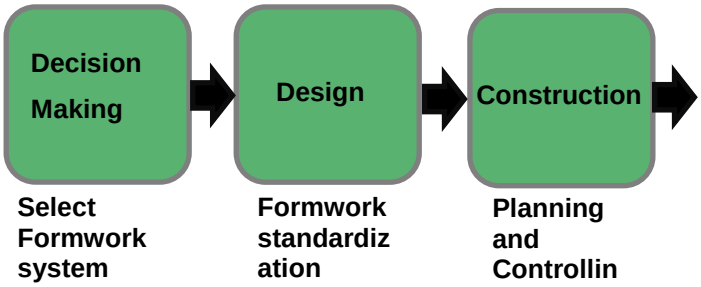


Figure 7: Project processes and LC implementation.

(Adapted from Figure 5-5, Martinez, 2016).

The first challenge faced during the project development is related to the customization of the houses. During the construction of some unit houses, with the intention to show them for the future clients, it was perceived by site workers and masons that the formworks system available does not suit properly to the different housing models. The usage of standard wood panels available in the market caused interruptions in the work flow, increasing the need of non-add value activities, as the construction of particular purpose formworks, and introducing the necessity of complete the cast-in-place concrete works with masonry works, in order to close the gaps in the structure caused by the lack of customized formwork panels.

The LC concepts implemented to solve this problem and increase the production efficiency are described below:

Reduce the share of non-value adding activities – during the pilot houses construction was evidenced that the formworks panels available were creating the need to add non-value activities to the construction process. The choice of more suitable formworks enabled a reduction in the number of this activities.

Reduce the cycle time – the use of appropriate and customized formwork panels had impact on the time reduction in the construction cycle.

Benchmark – this concept has crucial importance. The developer and construction professionals visited different construction sites that were applying different types of formwork panels for different purposes. The availability of data and the possibility to

see how other companies were developing their work increased the knowledge of the team and lead the decision for the most suitable formworks type to the project.

In his doctoral dissertation, Martinez describes in detail the process of decision making being applied in this project, including the literature review of different techniques and the social aspects of the process. The decision-making process and its social aspects will not be detailed in this master thesis.

The necessity to standardize the formwork process became evident after the design and construction of the pilot houses. With a degree of customized models of houses, the available formwork panels at the market caused the need to add non-adding value activities to the construction process, and had a negative impact on the cycle time and in the productivity.

During this process, the partnership between the design professionals and the supplier had a decisive role in the search for the optimum design of the formworks suitable to the construction site.

The author drew the standardization process as depicted in the figure 8.

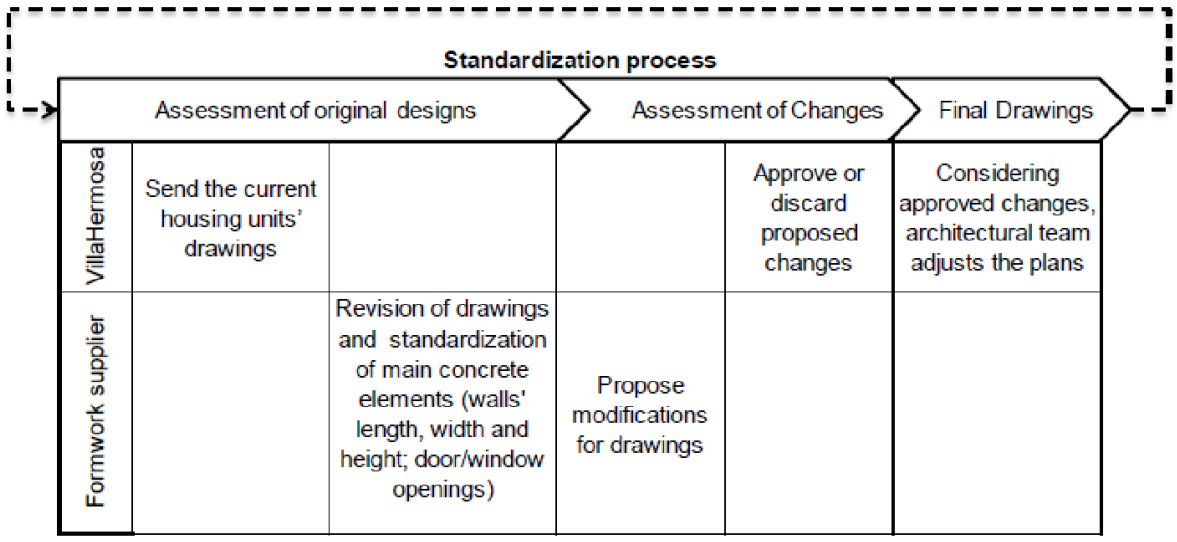


Figure 8: Formworks standardization process.

(Copied from Figure 5-20, Martinez, 2016).

After the construction of the pilot houses, the supplier has been involved in the design review and, with the adoption of the changes suggested, it was possible to

develop a set of two formworks suitable for the concrete works of 12 different models of houses. The flow of the construction, mixing different sizes of houses, was also balanced. This was done introducing a medium size house in the flow of construction among bigger and smaller sizes construction. This action has avoided that a set of formworks stood out on the use while the bigger houses were under construction.

The possibility of using just 2 sets of formworks for all the available houses models reduced the storage space needed and reduced the variation in the construction operations. One formwork set was used in houses with the maximum 67m² and the other set in houses until 100m².

After the formworks adjustment, it was necessary to balance the production flow. The work in small houses was flowing faster than the work in bigger units. The initial production scheme was the production of 7 big houses and 3 small houses as a work package. With this production flow, the workers involved in the production of small houses will reach the third work package at the 9th day of production, while the bigger houses team will still be working in the second work package.

In order to establish a more efficient work flow and avoid that the teams working in the smaller houses need to interrupt the work and wait for the bigger houses team to continue the construction of the 7/3 work packages, a medium-sized house was introduced into the flow. This house could be constructed with any of the formworks and the sales control provided the feedback in the amount of houses to be produced.

The author called this medium-sized house as wildcard house model and drew the balanced production flow, shown in the Figure 9.

As the time necessary for the production of the wildcard house was longer than the needed for the production of the smaller units, the team dedicated to the smaller houses could be designated to this production, after the completion of their first part of the work package.

This enabled the teams to be in pace in the production of the planned block of units and work package, avoiding any delay in the houses delivery, unnecessary waiting time by any of the production teams and idle time in the use of the formworks sets.

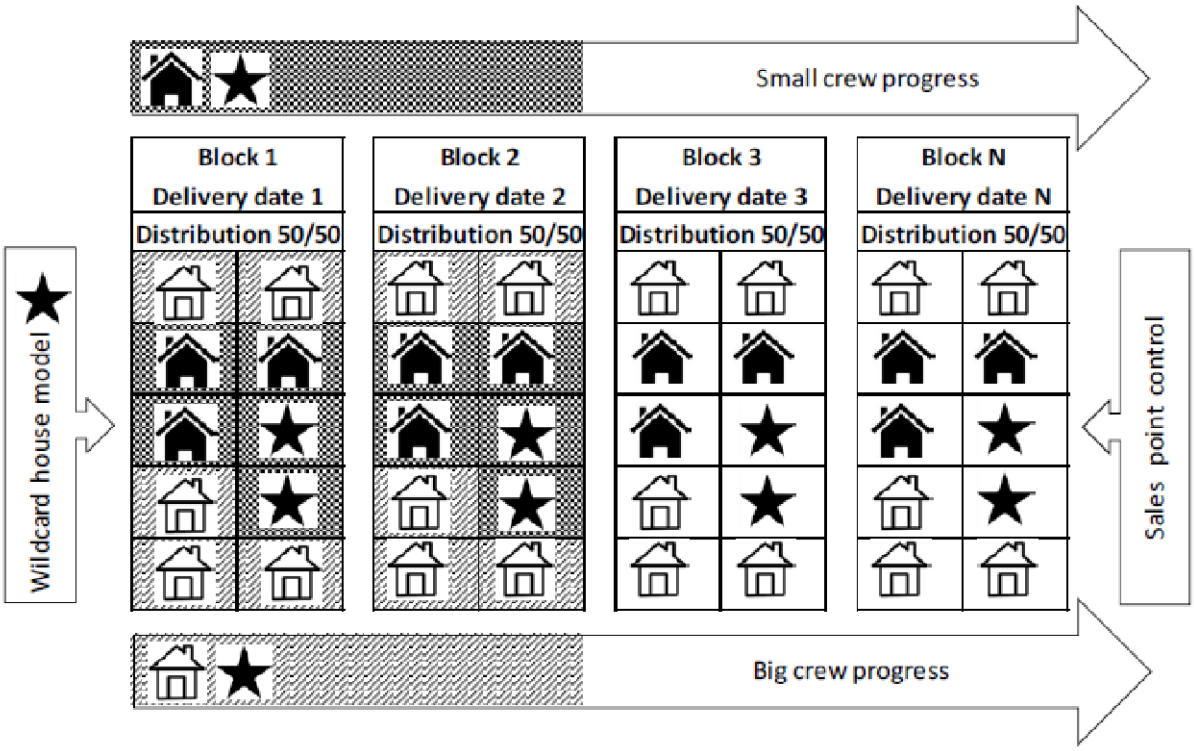


Figure 9: Balanced production flow.

(Copied from Figure 5-24, Martinez, 2016).

The author highlights a reduction of 25% on inventory and savings in the designed setup of the formworks. The Table 7 presents the values:

Item	Original Design	Improved Design	Reduction %
Number of pieces	3,360	2,492	-25.8
Total Cost USD	631,184	501,597	-20.5

Table 7: Result from design standardization.

(Adapted from Table 5-4, Martinez, 2016).

The level of customization in this project increased the construction process variability and complexity, which have a direct impact on planning and controlling the tasks. Tailored Information technology tools were developed to be used in this project to enable the controlling and monitoring of the construction.

According to the author, the reasons that lead developers to avoid customized houses are the economic feasibility of housing design that fits to individual requirements and the difficulty in reducing the costs when there is a low number of

repeated activities. However, from the customer point of view, a customized house has more add value, once it is linked to their expectations.

In this case study, the customizations impacted on the control of the budget and the plan, and the adoption of IT tools, as an ERP system, enabled a better information flow.

The dissertation quotes Nahmens and Bindroo (2011) to guide to the solution of this dilemma. They argue that the implementation of Lean Production and the IT through the production processes have the potential to facilitate a customization strategy and, yet, increase efficiency. Martinez (2016), affirms that this approach has the potential to increase value and quality in the production of affordable houses.

The tools also collaborate in the continuous improvement of the process, the IT department implemented changes in the reports stemmed from internal clients feedbacks, as different colors to identify finished activities from the ones that were still in progress. The automation on the controlling activities improved the coordination among planning, construction and budget teams.

Furthermore, the use of IT tools and the ERP system create a reliable database from the project, that can be accessed in the future to serve as bases and best practices.

In the conclusion, the author found that the implementations of the LC concepts increased in complexity during the project development phases. He established a direct relationship between the complexity of the implementation and the number of stakeholders, internal or external, involved. The Figure 10 depicts the found relationship:

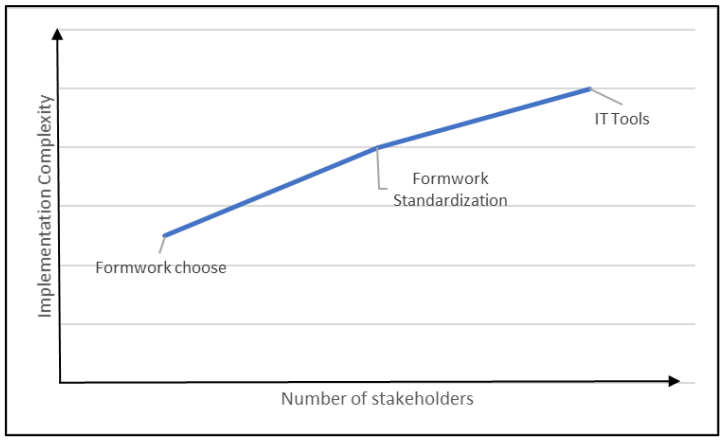


Figure 10: Implementation Complexity and number of stakeholders.

(Adapted from Figure 5-40, Martinez, 2016).

The complexity and the volume of data created from the interactions between the stakeholders increased, creating challenges to the LC concepts implementation. The commitment of the team was essential to the success of the implementation and enabled the coordination to become an interactive process, reflecting in positive results to the project.

The author focused during the dissertation on the variety on the products that has potential to reduce efficiency and enhance the challenges of planning and controlling the activities during the construction phase.

The communication among the teams and the coordination of the LC concepts implementation are emphasized as a source of problems and resistance when not exercised with focus and transparency. Falling in evidence, the focus on which result is expected from the LC implementation and what is the advantage of standardizing the process, can lead the team to create procedures that will not be applied, and the lack of tangible results can create barriers to the implementation.

The conclusions emphasize that the implementation of the LC concepts was valuable to face the project challenges, especially the ones related to the houses customization. The positive impacts on the construction site were measured and understood by the stakeholders. As the concepts were implemented in the initial phase of the project, and another 7 phases will be developed, the implementation process should be continued.

4.2.2) Case analysis

The case study presents a high level of complexity due to the customization of the affordable houses units. The customization is a challenge for establish repetitive tasks, standardization of the processes and reduce the variability during the construction tasks.

The implementation of the LC concepts brought tools to the project management to administer the risks related to the customization and reduce the process efficiency loss.

The construction of pilot houses to be shown to the future clients was took as an opportunity to evaluate the design flaws and study the construction flow. The feedback from the workers involved in the tasks enabled the understanding of the need for a customized set of formworks, once that the usage of the formwork standard panels available in the market was causing construction flow problems and introducing the necessity of non-adding value activities.

The benchmark done to know the available suppliers and the models used by other companies lead to a more concise choice of the supplier. After the choice, the partnership with the supplier during the design review assisted the fabrication of 2 suitable sets of formworks, capable of being used in 12 different type of houses.

The challenge related to the planning and controlling of customized construction was solved with the introduction of IT tools and an ERP system. During the usage of the tools the continuous improvement was essential to understand the team needs and make the necessary reports available.

In a construction project with so many challenges related to the houses units customization, the implementation of the LC concepts resulted in positive gains to the productivity, to the construction process flow, to the elimination of non-add value activities, to the decrease of necessary inventory of formworks and to the cost savings.

The main waste avoided was the labor waste. The simplification of the formworks sets during the design phase diminished the necessary time for assembly the parts, due to less complexity.

The commitment of internal and external stakeholders, as the IT team and the formworks supplier, during the implementation, resulted in benefits for the process result, including better quality of the finished houses.

The complexity to implement the LC concepts increased when the number of stakeholders rose. This can be analyzed as an effect of the increment on the complexity of the communication channels and the management of more expectations related to the results of the LC implementation.

The availability of tools and the team commitment in adopt the changes were the reasons to the success during the process. The understanding of the time necessary to reach the results and the involvement in the continuous improvement of the processes increased the positive results and the accepting of the introduced concepts.

The strategy of conducting mixed housing projects with units targeting the low-income demand and also units for middle and high-income families can make the affordable housing construction more attractive to private investors. This occurs because the profitability will be balanced and the risks related to governmental funding will be diminished. This approach also reduces the segregation by income and gentrification effects.

4.3) Nigeria

This study case was elaborated by S. Adamu, G.A. Howell and R. Abdulhamid and published by the International Journal of Scientific & Engineering Research Volume 3, Issue 12, in December 2012 with the ISSN 2229-5518.

4.3.1) Case Description

The study case analyses the application of Last Planner System in the construction of 500 affordable houses in Damaturu. The construction project was realized by Yobe State Government of Nigeria.

The authors emphasize the challenge faced by Nigerian construction industry in adapt and use the management techniques focused in eliminate waste and improve the final product value.

With the study, their aim is to compare the LPS with the traditional production method and analyze the actual status of the LC concepts, understanding and implementation in Nigeria.

The data was collected through direct participation in the construction site and interviews.

The Nigerian construction industry experiences a decline in profit margin despite the continuous increment on the demand for houses and general infrastructure.

With the intention of implementing initiatives on create supply for the house demands, Yobe State Government launched the construction project of 500 units of affordable houses. The target clients group was the low and very low-income population.

This project involved political leaderships, such as the state governor and the ministry of housing. The authorities addressed their concerns with the construction efficiency and effectiveness and involved the stakeholders in the decision-making process about the management approach. From these discussions, the

implementation of Lean Construction concepts emerged as a solution to the problems related to the final product value and the waste generated during the construction processes.

The authors emphasize the lack of knowledge and research related to Lean Construction concepts and how to adapt them to the Nigerian construction industry.

A literature review about Last Planner production system was conducted to foment the theoretical understanding necessary to the implementation in the construction site, the study case elaboration.

The adoption of management processes related to planning and controlling the activities is highlighted as the way to achieve the project objectives, as the designation of who will be responsible for the tasks and its results.

The construction of the 500 housing units occurred in different regions of the Yobe State, being the construction of 300 housing units in the state capital, 170 housing units in other state areas and 30 housing units in a headquarters zone.

The government wanted the project to be the pilot project of low cost houses, as a solution to the local lack of affordable housing issue.

The houses presented different designs, being 200 units of two-bedroom ground floor houses, 100 units of two-bedroom two floor houses and 100 units of three-bedroom ground floor houses. The construction process applied clay bricks.

The management of the construction of the 300 housing units in the state capital was divided in 6 management teams. Being each team responsible for the management construction of 50 housing units.

The management focus was to achieve the maximum added value in the final product. One of the teams, the one that the authors were part, applied LPS and the remaining five teams used traditional production management methods. The general project supervision monitored the performance of all the management teams.

The project master schedule was divided in three phases: main structure, roofing and finishing services. The considered working week was of 5 days. Each unit construction has a total duration of 120 days in the master plan. With the application of the reverse phase scheduling, the possible duration decreased to 90 days.

In the LPS management, the workers team dedicated to the production of one house from 7 until the maximum of 10 workers. The activities were planned focused in minimize, as much as possible, the workers idle time. The final production time for one unit house was between 65 to 72 days.

The teams applying the traditional management approach were not able to finish any house unit in less than 120 days. The teams dedicated to the construction of one unit house were composed from not less than 15 workers.

The production efficiency of the team applying the Last Planner System enabled the team to dedicate the production team to support the conclusion of the houses of the other teams.

Schedule	LPS	Traditional Management
Master Plan	120 days	120 days
RPS	90 days	-
Executed	65-72 days	>120 days

Table 8: Schedule comparison.

(Adapted from S. Adamu, G.A. Howell and R. Abdulhamid, 2012).

In the team conducting the LPS implementation, intensive study and training about the Last planner concepts were done. Other management tools supported the LPS implementation, as the discussion of the time needed in each activity, the comparison between the planned due dates and the real executed dates, and the involvement of the team in stretch the causes of failure and dedication in correct them.

Constraints to the implementation of the team motivation were considered important. Controlling and monitoring all the activities demanded time and dedication, and could became a tedious task. The subcontractors were not invited to participate in the scheduling and controlling process, and demonstrated a certain resistance in collaborate with the implementation process. The introduction of incentives was conducted to maintain the team committed with the implementation process.

The last planner sequence of implementation was adopted as the one described by

Salem (2005) and is shown in the Figure 11.

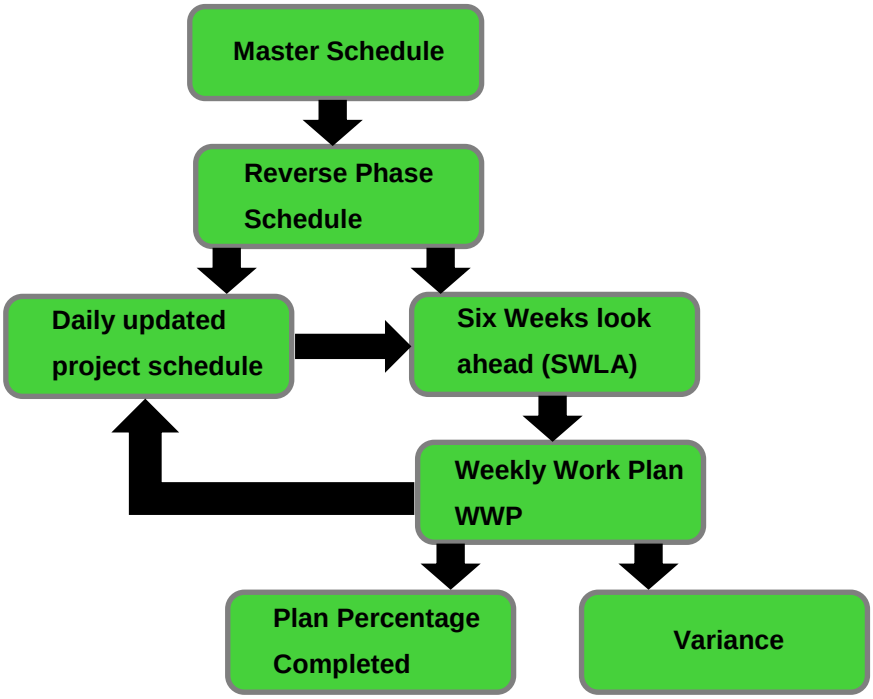


Figure 11: Last Planner Sequence.

(Adapted from Figure 3 S. Adamu, G.A. Howell and R. Abdulhamid, 2012).

The implementation process was conducted by the project manager with the production team involvement and support. The first phase was the elaboration of the master schedule. That was done based on the production team input and the experience in previous projects.

In order to enable the reverse phase schedule development, all the information about design, schedule and construction methodology was distributed to the team. Also, the team training in LPS concepts took place before the RPS meeting.

The team involvement in the RPS production was considered by the authors as a factor of success to the implementation.

During the RPS meeting the team gave feedback about the logic in the activities execution sequence. The production critical path was identified and the necessary buffers were added to the most critical activities. After the RPS meeting, a detailed schedule was assembled, considering the constraints to the production flow.

The six weeks look ahead, SWLA, contemplated the analysis of the constraints and

was distributed during weekly meetings with the production team.

During these weekly meetings, the distribution and discussion of the Weekly Work Plans occurred. These meetings were also dedicated to the discussion of issues regarding the planning processes and foresee constraints related to labor, safety, materials and construction flow.

The project manager was responsible for update the WWP schedule and control and analyze the variances and their causes. The Plan Percentage Completed was calculated and communicated to all the team involved in the process.

In the case study results, the authors point out that the SWLA approach enable the identification and elimination of constraints with time to assure the execution of the work as previously planned. The information distribution provided the team tools to understand the workflow planned and the possible interruptions.

The WWP and the weekly meetings made possible a close monitoring of the variances between the planned activities and the executed ones. The Plan Percentage Completed was targeted to not be below than 70%, and due the management approach the value was achieved.

In the paper conclusions, the authors emphasize the positive impact of the implementation of the LPS in the project. There was significant contribution in maintain the planned date and in avoid interruptions in the workflow.

The authors address the concern about the Lean Construction Concepts and LPS in Nigerian Construction industry, motivating the stakeholders involved in the construction industry in Nigeria to train their staff and implement Lean Construction concepts.

The Nigerian Government is interested in disseminating the Lean Construction concepts and continue to apply them in the construction of affordable houses. The main target is to contribute for a more efficient construction industry and to combat the waste during the construction process.

4.3.2) Case analysis

The case study presents an interesting implementation in the Nigerian construction industry. The project is an introduction of the Lean Techniques in a governmental project of affordable housing and involved the professionals builders and important political representatives, as stakeholders.

The challenges during the implementation included the lack of knowledge about LC and the necessity to adapt these concepts to the reality of the local construction industry.

The management approach was focused in diminish the non-adding value activities during the production and decrease the waste. The main tool applied focused on the activities in scheduling and controlling with the application of Last Planner System.

The construction project was divided in 6 management teams and only one team implemented the LC concepts.

With the team involvement, the management, applying the LC concepts, was able to decrease the number of workers in the production team, eliminating labor waste and developing the construction activities in less time, when compared to the teams applying the traditional management approach.

As the case study is just part of one pilot project of affordable housing, it is not possible to affirm or to forecast the success in the implementation as an assured result in the entire Nigerian industry. Nevertheless, it is possible to affirm that the LC concepts can be adapted to the local industry and result in benefits to the project profitability.

The Government involvement in the implementation of LC concepts can bring benefits in spread the knowledge and make the implementation by the local construction industry more attractive.

The communication of the results of the LC implementation through technical magazines and local conferences can increase the Nigerian industry awareness about the LC concepts and the benefits of the implementation.

As the LC concepts were new in the project of the study case a certain level of

resistance to the implementation occurred, especially related to the level of documentation, production and communication management.

4.4) Recommendations

During the implementation of Lean Concepts is not unusual a certain level of resistance, especially from the workers with lower level of schooling. In order to decrease the resistance to the usage of training programs, discussing and spreading the knowledge about the concepts is successfully applied. Other important approach is to involve the workers in the implementation and communicate the positive results, as a way to motivate them to continue with the process.

Other important challenge is the lack of standards for the processes and activities. When this occurs, the implementation of LC concepts need more time to evidence any positive result, once that it is, at first, necessary to organize the processes and create the standards.

The lack of standards to accomplish the work is commonly associated with waste and team demotivation. Thus, the adoption of standards can contribute to minimize or avoid the waste, to enable the measurement understanding and to reduce the processes variability.

Motivating the team to work in partnership with the suppliers can cause positive impacts during the design and enable a better working flow during the construction process. If the supplier of a customized item gets involved in the early stages of the design, it will be possible to reduce the number of design reviews after the work completion and also affect positively the design cycle time.

Choosing a pilot process can be an excellent technique to maintain the motivation of the team. After the implementation of LC to one process, there will be a better understanding of all the work needed, and then some time will be necessary before the positive results can be reached.

The partnership with suppliers can facilitate the processes standardization. When the supplier is able to offer advice during the design phase, the probability of an understanding of the project needs and the offer of the most suitable solution increase.

When possible, the construction of a pilot house is highly recommended. During the construction of the pilot unit will be possible to evaluate the construction flow and

introduce changes in the project that will bring benefits during the construction continuation.

The usage of IT tools and ERP systems during the implementation of LC concepts have potential to increase the quality in the information management, resulting in more transparency in the communication among the team and reducing the time needed to supervise the great amount of information.

Being updated with the available IT tools in market and understanding how they can be customized to the particularities of each construction site can enhance the management. The use of benchmark enables to understand how the other companies are applying the new technologies and which benefits were already measured.

The participation of the stakeholders in the LC implementation must be active and supportive. During the implantation process, when the challenges start to appear, the stakeholders should support the implementation process to go on, emphasizing the benefits and advantages of the Lean Construction approach.

During the implementation process the expected results should be settled. They should be measurable and understandable for all the team involved. After the beginning and also after the implementation measurements must occur. The results must be communicated to all the involved ones and the communication needs to be clear and transparent. The complain that the results are not clear communicated and about the lack of objectivity to communicate the expectations with the LC implementation is not uncommon and generate demotivation, resistance and mistrust in the team.

The team’s motivation during the implementation of LC concepts is directly related to the success of the process and linked to the communication quality and objectives transparency. Having a communication plan and strategy that encompasses all the implementation process is highly recommended, just as the review of this plan. The feedback of the team involved in the implementation process must be an indicator of how the communication is working and the flaws in the processes.

The construction of mixed housing projects, with units targeting the low-income demand and also units for middle and high-income families, can make the affordable

housing construction more attractive to private investors, once that the profitability will be balanced and the risks related to governmental funding will be diminished. This approach also reduces the segregation by income and gentrification effects.

Once that the construction of affordable housing projects still depends, in the major of the cases, of governmental funding, the involvement of political leaderships can bring the industry attention to the implementation of LC, especially in projects and countries were the LC is starting to be implemented, as the government advertisement of the LC implementation and the positive results of it can raise the interest of the construction industry in implement LC.

In order to attract more private investment to affordable housing projects, disseminating the positive results of similar projects that implemented Lean Construction can increase investors interest in funding such projects.

In countries where the LC initiatives are starting, the government can incentive the construction industry with trainings and educational programs about the Lean Construction.

Government and professional associations should encourage the knowledge exchange, especially with benchmark, about projects implementing Lean Construction. The construction industry stakeholders will be able to learn from each other experiences in the implementation and be prepared for the constraints that will appear when the implementation process starts.

The participation in conferences and professional meetings about Lean Construction have potential to prepare the interested team to the implementation process. In this type of meeting is possible to have contact with success and failure cases, having contact with the best practices developed so far.

The implementation process has more success probability when the team is committed with the necessary effort, as the main tool to assure and maintain the commitment is the communication. The access to the necessary information in the needed time and the dissemination of the results are very important. When the team is dedicated but has no information about how they will be evaluated or which result is expected from their work, the demotivation will grow. Also, when they are not communicated about which was the result of the final measurements, they will have

the impression that all the effort they have done brought no result at all.

The recommendations wrote in this chapter are based on the case studies analyzed in this master thesis. They are not “a must do guide” for the lean construction implementation in affordable housing projects, but they reflect how the main constraints to the implementation were solved.

They also reflect important initiatives to the success of the implementation in the previous described and analyzed study cases.

Once that every construction project has particularities about the design, the implementation country and local industry, considering this particularities into the Lean Construction implementation process is necessary to guide the entire process.

5) Research questions answers

This chapter presents the answers to the research questions. These answers encompass the research findings after the literature review and the critical analysis of the existing study cases.

1) What is lean construction and can it be used as a solution to produce low-cost housing?

Lean construction is the application of the Toyota Production System philosophy in construction industry.

The TPS philosophy and the Lean Concepts emerged in the manufacture industries, as management tools to increase the profit through the production flow analysis, the identification and classification of waste, in order to eliminate the waste and increase the productivity, the profit and the efficiency.

Once that the efficiency and the waste are also issues for the construction industry, researches to adapt the Lean Concepts to be applied in the construction industry became a trend during 1990's. The first researcher to analyze the possible benefits in applying TPS in the construction industry was Ari Koskela in 1992, in his paper "Application of the new production philosophy to the construction".

After the analysis of the three existing study cases presented in this master thesis, it is possible to conclude that the application of Lean Construction philosophies for the construction of low-cost housing is not only possible but very recommended.

The implementation of Lean Construction concepts during construction projects of low-cost housing has potential to increase efficiency and eliminate waste during the processes, increasing the profitability, the efficiency and the final product quality.

The private investors tend to avoid investments in affordable housing projects due to the low profit margins. In this aspect, the implementations of Lean Construction concepts have the potential to attract more investment to projects to supply the increasing demand for affordable houses.

2) Is it possible to list the benefits of the Lean Construction management to affordable housing construction? Which are they?

After the analysis of the case studies presented in this master thesis, it was possible to identify benefits in all the three construction projects.

In the Brazilian case study, the waste in materials and labor was significantly diminished. With the measurement of the amount of labor hours wasted and the volume of materials wasted was possible to identify the monetary value of the waste. The implementation of Lean Construction concepts eliminated the waste and increased the processes efficiency. With the waste elimination, the profitability increased.

In the Nigerian case study, the implementation of Last Planner System led to the better understanding of the production flow. As a result, the time required for the construction decreased. Considering the demand for affordable housing, the possibility of developing this housing projects in less time has great impact on society. Once that, as described in the literature review, the lack of housing produces undesired effects in the society, as health issues and the increasing in violence and crime rates.

In the Ecuadorian case study, the implementation of Lean Construction concepts enabled the offer of customized house units to clients without loss of productivity. This project presented challenges related to the customization of the houses and the Lean Construction approach brought benefits to the management of the project. The establishment of a partnership with the formwork supplier and the detailed study of the workflow enabled the elimination of waste related to the space of inventory, the adjustment of the workflow to avoid the labor waste and increase the add-value for the final client, once that the customization of the house units was possible with minimal decrease in the production efficiency.

From the case studies analysis is possible to list the following benefits from the implementation of Lean Construction Concepts in projects for affordable housing:

- Identification and elimination of labor waste;

- Identification and elimination of material waste;
- Decreasing in the inventory space necessary;
- Increase of profitability due to the savings possible with waste elimination;
- Decreasing in the production time;
- Better understanding of the processes and the production flow;
- Less variation of processes due to standardization;
- Avoid productivity losses in projects with high level of customization;
- Development of customized solutions due to supplier involvement and benchmark.
- Better planning and controlling of the productivity with the adoption of IT tools.

3) How could Lean Construction support affordable Housing?

In the answer of the previous question, the benefits found and measured in the existing study cases that were analyzed during the development of this research were listed.

The implementation of Lean Construction concepts can support affordable housing projects in different manners.

The more obvious benefits are the ones related to the production. The standardization of the processes can eliminate the variation and establish clear measurements to the activities. The better understanding of the production flow enables the identification and elimination of waste, and in this impact, the elimination of materials is easily identified by the team involved. More efficiency in management of materials and space impacts in less inventory.

There are also benefits for the project when planning tools, as the Last Planner System, are adopted. The monitoring among the planned and executed activities allows the identification of the causes of late and increase the possibility of avoiding the future occurrence. The adoption of a Look Ahead planning approach supports the team to foresee possible constraints in the activities planned in a time that permits the actions to be taken and assure the production flow.

Once that the adoption of Lean Concepts increases the affordable housing projects

efficiency and profitability, these concepts can support this type of project attracting more private investors to this market share.

Affordable housing projects are mainly dependent of governmental investments, and the principle reason that private investors resist to finance these projects is related to the low profitability commonly associated with affordable housing construction.

With the adoption of Lean Construction concepts, the profitability and efficiency in the construction of affordable housing projects has the potential to enhance and turn the market more attractive for private investors.

This would diminish the pressure in the government related to the solution of issues associated to housing policies and propelling the construction industry.

The demand for affordable housing is a global issue and increases constantly. This market share can become attractive to the AEC industry, that suffers with efficiency and profitability issues for a long period.

The creation of incentives to adopt the Lean Construction concepts and to invest in affordable housing projects can bring positive impacts for a market share of the construction industry that has a great potential for development.

4) Are there difficulties to implement the Lean Construction techniques to the construction of affordable housing? Which are they?

The benefits of the Lean Construction principles implementation were listed and highlighted in the answers of the previous questions. But the challenges faced during the implementation processes are also important and can cause the failure of the LC adoption.

Each project presents a certain level of particularities and the challenges faced during the implementation process can vary in accordance with the project location, the team designated for the process and the stakeholders involved. Nevertheless, some challenges and barriers are commonly reported during the implementation of LC concepts.

The challenges faced for the adoption of LC principles in projects for the construction

of affordable housing do not differ from the ones faced during the implementation of the concepts in construction projects of housing for medium and high-income families or even industrial and commercial projects.

The most commonly reported barriers are:

- resistance to the implementation of measurement systems;

- lack of commitment with the implementation process, equally from the team involved, the stakeholders and the high management actors;

- fear of being responsible for the flaws;

- absence of appropriate understanding about the LC principles;

- deficiency in understand the need of implement managerial changes;

- the assumption that the construction projects particularities inhibit the adoption of standardized processes and management tools;

- insufficient funds for the implementation process;

- poor skills in team working;

- inefficient support of the stakeholders to the implementation process;

- resistance to the cultural shift necessary to the Lean Construction implementation.

5) Is possible to minimize or avoid this implementation challenges? How?

Besides the number of challenges that appear during the implementation of Lean Construction implementation, the knowledge about them and the adoption of managerial actions can avoid and minimize these challenges and their negative impact during the process.

The section 4.4) Recommendations of this master thesis describes in detail some actions that can be taken to overcome the challenges previously listed and assure the success in the implementation process of LC principles.

These recommendations will be listed in a summarized manner in the next paragraphs.

- To decrease the resistance, the usage of training programs to discuss and spread the knowledge about the concepts is successfully applied;
- Involve the workers in the implementation and communicate the positive results, in order to motivate them to continue with the process;
- Organize the processes and create the standards;
- Motivate the team to work in partnership with the suppliers;
- Choosing a pilot process can be an excellent technique. After the implementation of LC to one process, a better understanding of all the work needed will be possible. Also some time will be necessary before the positive results can be reached;
- The partnership with suppliers can facilitate the processes standardization;
- The construction of a pilot house is highly recommended. During the construction of the pilot unit will be possible to evaluate the construction flow and introduce changes in the project that will bring benefits during the construction continuation;
- The usage of IT tools and ERP systems during the implementation of LC concepts have potential to increase the quality in the information management;
- The use of benchmark enables to understand how the other companies are applying the new technologies and which benefits were already measured;
- The participation of the stakeholders in the LC implementation must be active and supportive;
- During the implementation process the expected results should be settled. They should be measurable and understandable for all the team involved;
- Having a communication plan and strategy that encompasses all the implementation process is highly recommended;
- the construction of mixed housing projects, with units targeting the low-income demand and also units for middle and high-income families can make the affordable housing construction more attractive to private investors;
- Disseminating the positive results of similar projects that implemented Lean Construction can attract more private investment and increase their interest in funding affordable housing projects;
- Government and professional associations should encourage the knowledge

exchange, especially with benchmark, about the projects implementing Lean Construction;

- The participation in conferences and professional meetings about Lean Construction have potential to prepare the interested team to the implementation process;
- The implementation process has more probability of success when the team is committed with the necessary effort, the main tool to assure and maintain the commitment is the communication.

The recommendations wrote in this chapter are based on the case studies analyzed in this master thesis. They are not “a must do guide” for the lean construction implementation in affordable housing projects, but they reflect how the main constraints to the implementation were solved.

They also reflect important initiatives to the success of the implementation in the previous described and analyzed study cases.

Once that every construction project has particularities about the design, the implementation country and local industry, considering this particularities into the Lean Construction implementation process is necessary to guide the entire process.

6) Conclusions

The lack of appropriate and affordable housing is a global problem faced by developing and developed countries, and dedicating financial resources and policies to the issue will bring benefits not only to those who are in need of a house, but also will cause positive side effects to the society and to different aspects of the government's costs.

With the current challenges for the AEC industry, as high levels of competition, low profit margins, increasing in resources prices, especially human resources and the market demand for projects constructed in shorter time, with the expected quality and within the budget, the implementation of LC concepts, techniques and tools has become a managerial need.

When comes to the construction of affordable housing, these challenges have even greater impact. Once this type of project normally faces enormous budget and resources constraints, they are known for lower profitability and this impact on the project quality during the entire project development.

The implementation of LC concepts, techniques and tools during the projects for the construction of affordable housing has the potential to transform these projects and make them more attractive for the AEC industry.

With this implementation is possible to understand the construction flow, monitoring where, during the processes, the waste is occurring and take the necessary actions to avoid that the profit becomes extinguished by the waste. It also enables the correct allocation of resources to execute the tasks, helping to prevent the over allocation or the delays due to the lack of resources.

The success for the construction of affordable housing for the AEC industry perspective is strongly related with the implementation of Lean Construction.

The case studies presented in this master thesis emphasize the positive results that were possible due the implementation of a Lean Construction approach. In these cases, the benefits were measured and resulted in direct better financial results.

The challenges faced during the LC implementation for the construction of affordable

housing do not differ from the ones faced during the implementation for the construction of houses for middle and high-income families.

The main challenges are related to the team's commitment to the implementation, the team's motivation, the general understand of the need of the changes to be introduced, the communication management during the process and the cultural shift inside the companies.

These challenges were also visualized during the implementation of TPS in car manufactures in the early 1970s.

From this, it is possible to conclude that the human factor is the main cause of failure when implementing a new production philosophy. This information leads to the need of training programs, good communication strategy and team motivation as tools to increase the success chances.

In projects where the team's involvement is high and the company, stakeholders and workers are committed with the LC implementation, positive results can be always measured.

As affordable housing is still very depending of government's policies, the introduction of regulations regarding the adoption of LC concepts can be beneficial to the contractors and to the government, leading to more efficient projects and more profitable results.

Working with mixed housing projects, with units targeting the low-income demand and also units for middle and high-income families, can make the affordable housing construction more attractive to private investors, once that the profitability will be balanced and the risks related to governmental funding will be diminished. This approach also reduces the segregation by income and gentrification effects.

Besides the Lean Construction techniques have now almost 25 years of development, the application in some countries and some fields of the construction industry is still young. The initiatives have less than 10 years in African countries and during the development of this research the cases related to the Lean Construction implementation available are not older than 5 years.

The implementation of LC in projects of construction of affordable houses has great potential to produce positive impacts. Through the elimination of waste in materials

and labor, decrease of idle time and non-add value activities during the construction processes, the management of this type of project construction can become more effective, impacting the project profitability.

From the time necessary for the construction perspective, a better construction flow can reflect in a decrease of the total time necessary for the construction, impacting in supplying the crescent demand of affordable housing in shorter time and also in savings due to the less time necessary of management crew in the construction sites.

The AEC industry, especially in the last decade, struggle with profit margins and the housing issue continues to increase. The construction of affordable housing has not only the potential of diminish the lack of housing problem, but also become an interesting business segment to the AEC industry and its investors.

Good management tools need to be applied to enable this development, and Leans Construction has brought positive results in projects of affordable housing in different countries.

The lack of information about case studies implementing the LC in the construction of affordable houses in developed countries was noticed during the execution of this master thesis. Once that European countries and United States of America also struggle with the lack of affordable houses and have projects to build this type of house, the lack of papers published about the implementation of LC in affordable housing projects caught the attention of the author.

It is not possible to understand if such projects do not exist, if they are not disseminated or if the industry fully applies the LC concepts, including in affordable housing projects.

6.1) Recommendations for Future Studies

- Development of measurable indicators of the social impact of the lack of appropriate and affordable housing;
- Analysis of the link between the lack of appropriate and affordable housing and local violence indexes;
- Analysis of the link between the lack of appropriate and affordable housing and health problems;
- What is the level of implementation of Lean Construction for the construction of affordable housing in different countries and segments of the AEC industry;
- Which are the particularities in the affordable housing projects that affect the LC implementation;
- Research on the long-term results of the LC concepts;
- Measurement of results after LC implementation in periodic frequency;
- Case studies related to the application of LC in affordable housing projects;
- Market research on the interest in investing in affordable housing;
- Which are the factors that inhibit the private investments in affordable housing projects;
- Purposes to attract investors to affordable housing projects.

Declaration of Authorship

I hereby declare that the attached Master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Appendix

Appendix A

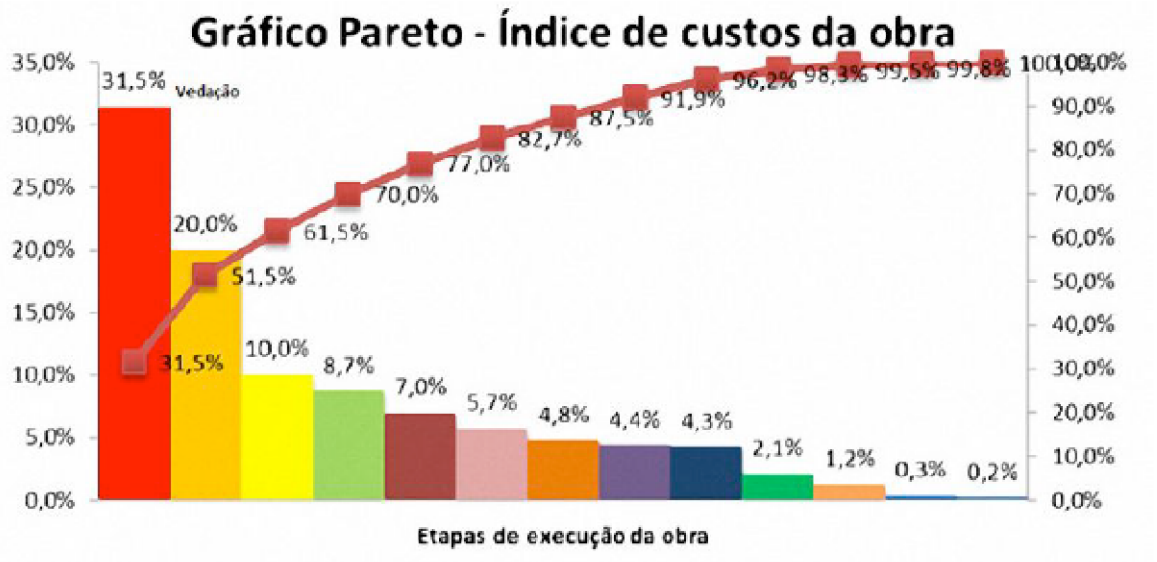
Brazilian Study Case important data collected Published by the authors.

Indicadores de Perdas Global - PMCMV2 .
Regional - Agreste

Município	Categoria	U.H	Recurso de obra	Perda de Materiais	Perda de Mão de Obra	Perda Global	Valor do Projeto
Município A	Empreendimento	40	liberado	21,00%	14,00%	17,50%	1.000.000,00
Município B	Empreendimento	31	liberado	18,00%	20,00%	19,00%	775.000,00
Município C	Empreendimento	43	liberado	22,00%	19,00%	20,50%	1.075.000,00
Município D	Empreendimento	44	liberado	17,00%	16,00%	16,50%	1.100.000,00
	Total	158					3.175.000,00

Fonte: A3 Engenharia (2013)

Figura 4 – Gráfico Pareto com percentual de perdas por etapa



Fonte: O autor (2013)

Figura 6 – Quantidade de insumos usados na obra

Quantidade de Insumos Utlizados na Obra - PMCMV2 .
Serviço - Vedação

Alvenaria de vedação (1:3:7) e=12mm P=1h/m² — 98,53m²

ETAPAS DO SERVIÇO (VEDAÇÃO)	Qtd. Prevista	Qt. Utilizada	Índice de Perda (%)
Cimento (saco 50kg)	5,00	7,00	28,57
Cal (m³)	0,80	1,30	38,46
Areia (m³)	1,50	2,60	42,31
Tijolo (unidade)	2550,00	3100,00	17,74
OBS: Material Considerado para Vedação de apenas 1 U.H			

Fonte: A3 Engenharia (2013)

Figura 7 – Tempo para execução dos serviços

Tempo de Execução nas Etapas dos Serviços - PMCMV2 .
Serviço - Vedação

Alvenaria de vedação (1:3:7) e=12mm P=1h/m² — 98,53m²

ETAPAS DO SERVIÇO (VEDAÇÃO)	Tempo Exec. Previsto	Tempo Exec. Utilizado	Índice de Perda (%)
Impermeabilização do Baldrame (dia)	0,50	0,60	16,67
Alvenaria Elevada com Tijolos (dia)	3,30	4,80	31,25
Junta de Alvenaria (dia)	1,20	1,90	36,84
OBS: Material Considerado para Vedação de apenas 1 U.H			

Fonte: A3 Engenharia (2013)

Figura 9 – Quadro resumo de perdas

Quadro resumo das perdas (PMCMV2) - Etapa Vedação

Alvenaria de vedação (1:3:7) e=12mm P=1h/m² — 98,53m²

PERDAS NA VEDAÇÃO	CUSTO UNITÁRIO	QUANT. UTILIZADA	VALOR TOTAL	Índice de Perda (%)	VALOR DA PERDA
CIMENTO(saco)	R$ 23,20	7,00	R$ 6.983,20	28,57%	R$ 1.995,10
TIJOLO(unidade)	R$ 0,45	2900,00	R$ 56.115,00	17,74%	R$ 9.954,80
MÃO DE OBRA(diária)	R$ 180,00	7,30	R$ 56.502,00	31,51%	R$ 17.803,78
OBS: Material Considerado para etapa de Vedação				TOTAL	R$ 29.753,68

Fonte: A3 Engenharia (2013)

Appendix B

Ecuadorian Study Case important photos and figures of the standardization process as Published by the author.

Figure 5-6: Formwork system mismatch

Figure 5-7: Masonry in the gable (from the interior)

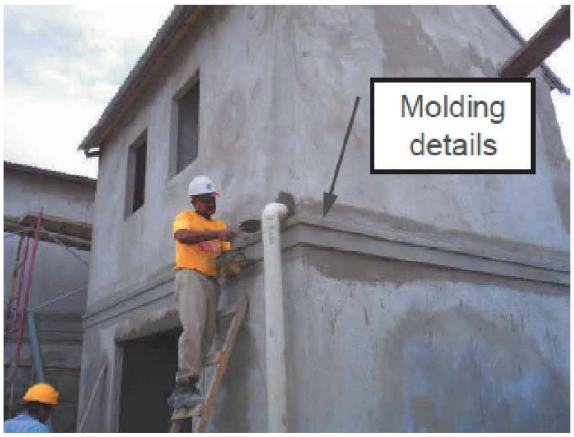


Figure 5-8: Additional molding operation

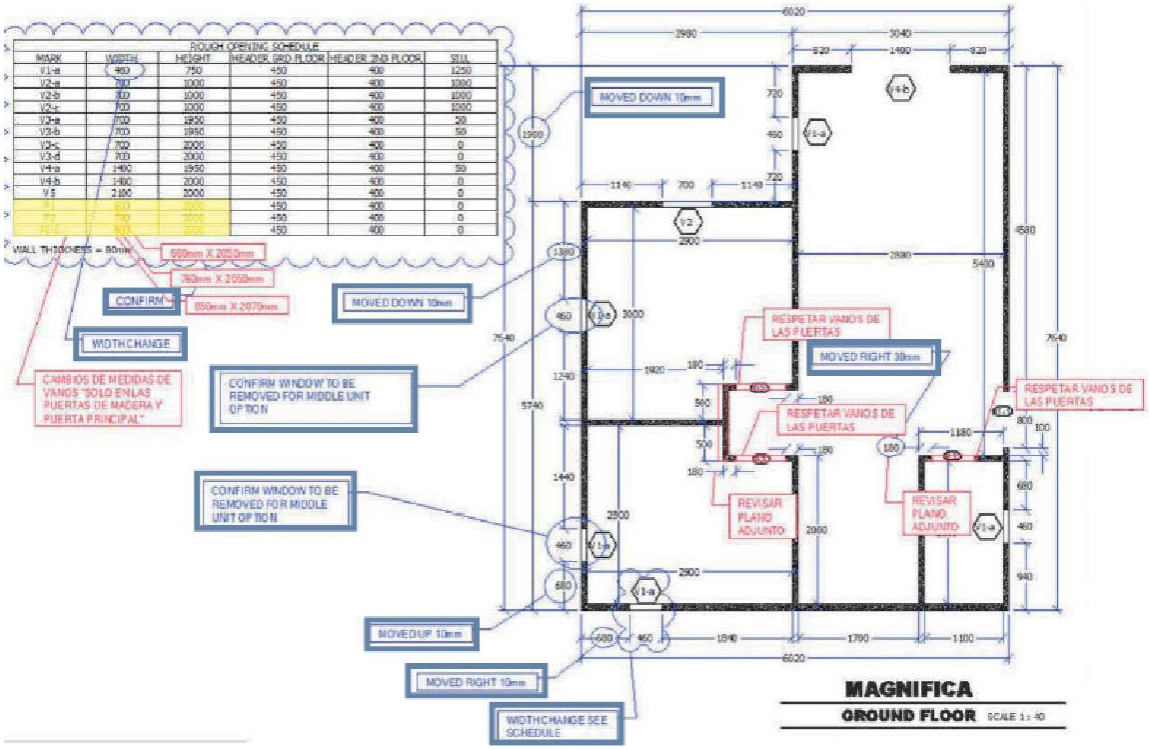


Figure 5-21: Details of the standardization process

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